Status of RHIC-Spin Program

OUTLINE

- Motivation / long-term goals of RHIC-spin program
- Who we are / new members of RHIC spin collaboration
- Accomplishments from Runs 2,3
- Issues for the future
- Progress towards Run 4 and beyond

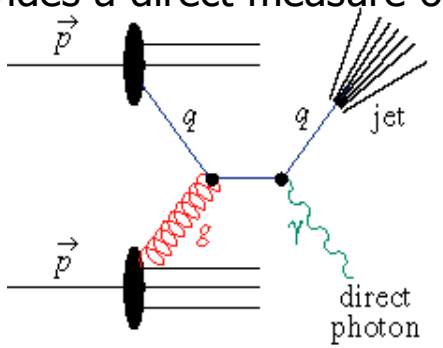
L.C. Bland, for the RHIC Spin Collaboration
Brookhaven National Laboratory
RHIC Program Review, 9 July 2003

BROOKHAVEN NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

Gluon Contribution to the proton's spin

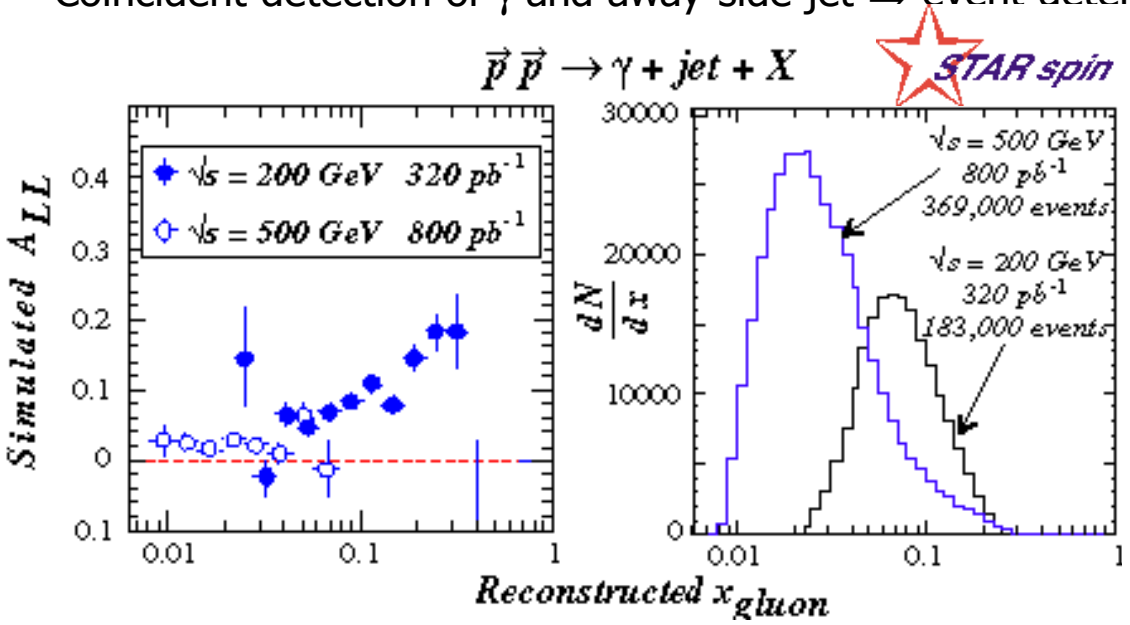
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$$\vec{p} + \vec{p} \rightarrow \gamma\,(+\,jet) + X$$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) with longitudinally polarized protons

$$P_{b1} P_{b2} A_{LL} = \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{b1(2)}$ — *beam pol'n (~70%)*

$N_{++(+-)}$ — *equal (opposite) helicity yield*

R — *relative luminosity*

Interpret measured asymmetry within leading-order pQCD

$$A_{LL} = \overbrace{P_{part.\,1} P_{part.\,2}}^{\text{parton pol'ns.}} \hat{a}_{LL} = \frac{\overbrace{\Delta f_1}^{\text{pol struct fncs.}}}{\underbrace{f_1}_{\text{unpol struct fncs.}}} \frac{\Delta f_2}{f_2} \hat{a}_{LL}(\hat{s}, \hat{t}, \hat{u}) \rightarrow \frac{\Delta G(x_g)}{G(x_g)} A_1^p(x_q) \hat{a}_{LL}$$

QCD Compton

Measured in polarized deep-inelastic scattering

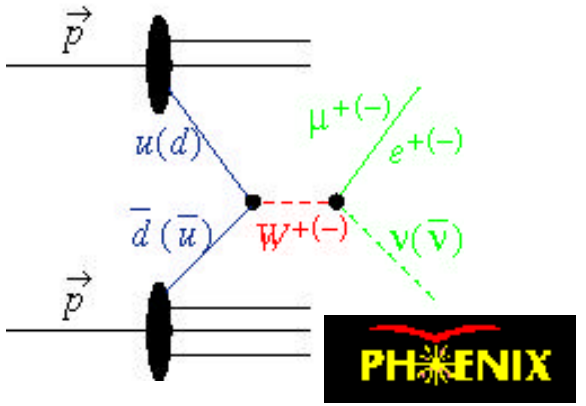
pQCD result for specific process

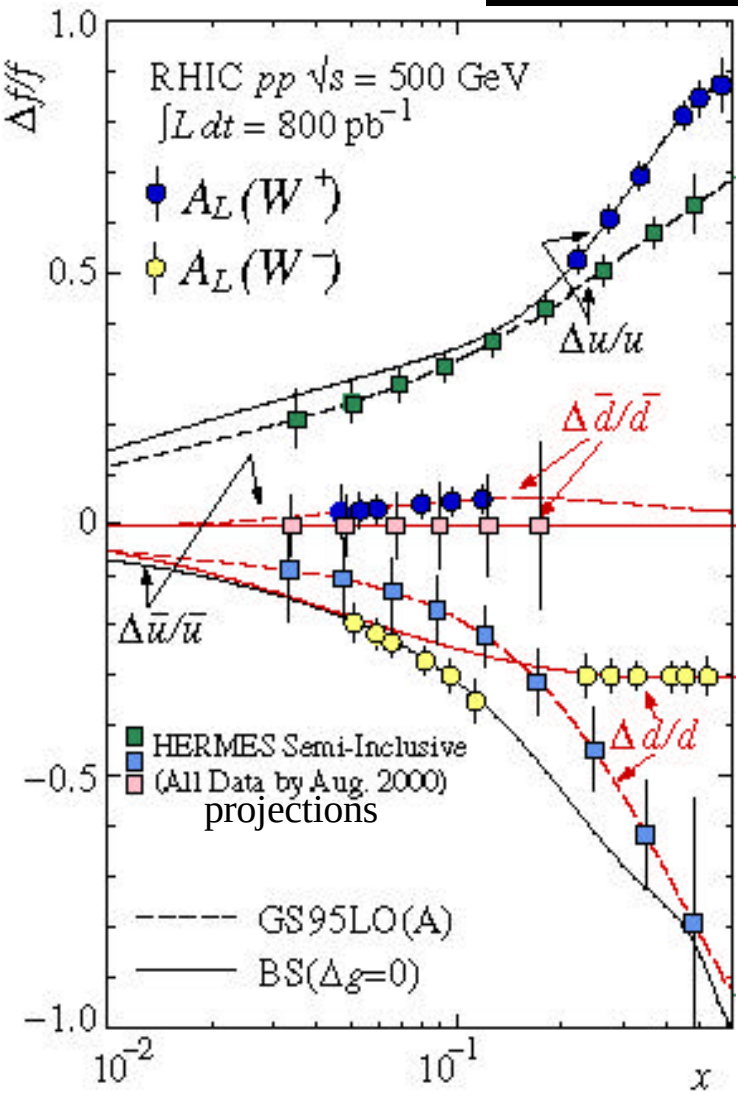
gluon polarization

Flavor Decomposition of the proton's spin

- W ± production probes flavor structure analogous to ν deep inelastic scattering.
- Polarized proton beams allows the measurement of (the expected large) parity violation in W ± production.
- Forward μ,e detection (dominated by production of W 's with large longitudinal momentum) gives direct probe of quark (antiquark) polarization:

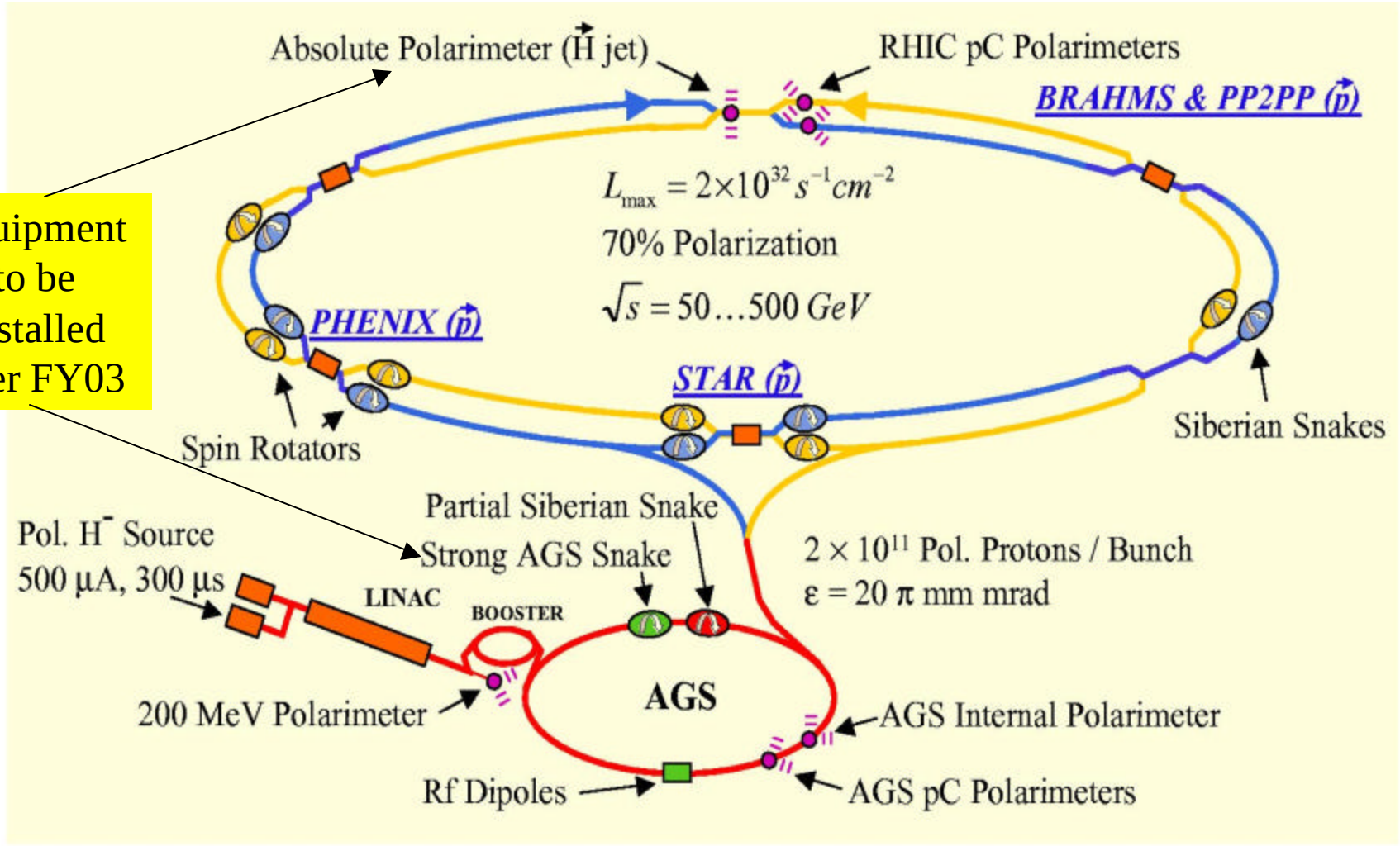
$$A_L \xrightarrow[x_1 >> x_2]{} \begin{cases} \dfrac{\Delta q(x_1)}{q(x_1)}, & \text{when lepton is mostly parallel to the polarized proton} \\ \dfrac{\Delta \bar{q}(x_2)}{\bar{q}(x_2)}, & \text{when lepton is mostly antiparallel to the polarized proton} \end{cases}$$





BROOKHAVEN NATIONAL LABORATORY

Polarized Proton Operation at RHIC



Equipment to be installed after FY03

Equipment/developments for run 3 (3/03 → 5/03)…

- Siemens motor generator in AGS
- CNI polarimeter in AGS → fast feedback
- β*=1m 'squeeze' after acceleration
- spin rotators → longitudinal polarization

What is required for a spin experiment at RHIC?

(a summary of the multiple concurrent experiments)

Stages of the RHIC-spin Project

Run 2 (12/01→1/02) Run 3 (3/03→5/03)

Concept → Learning → Production

- Production of high-energy/intensity/polarization proton bunches that collide
  - ⇒ A successful accelerator physics experiment employing 'snakes',rotators,etc.
  - Rarest probes require P_{beam}=70% and $\int \mathcal{L}\, dt$ = 320(800) pb^{-1} at $\sqrt{s}$ = 200(500) GeV
- Large experimental facilities capable of detecting hadrons/jets, γ, $e^{\pm}$,$\mu^{\pm}$ ...
  - ⇒ Experimental sophistication comparable to other colliders (Tevatron, HERA,...)
- Polarimeters to monitor polarization and establish its absolute magnitude
  - ⇒ Coulomb-nuclear interference / polarized gas jet target / local polarimeters
  - Require $\Delta P_{beam} / P_{beam} \sim 5\%$
- Interaction-region monitors of spin-dependent relative luminosity
  - ⇒ Precision experiments to minimize systematic errors in final answer

BROOKHAVEN NATIONAL LABORATORY

RHIC Spin Collaboration Organization

- **RHIC Spin Collaboration** (Spokesman: G. Bunce)

Develops overall spin plan; forum to coordinate spin issues for RHIC accelerator and experiments.

Spin physics is an integral part of the goals of the STAR, PHENIX and pp2pp experiments.

- **RHIC Accelerator Spin Group** (Spokesman: T. Roser, Project Manager: W. Mackay)

Accelerator physics for spin (Siberian Snakes, Spin Rotators,`Spin Flipper'); polarized ion source; polarimeters.

- **RIKEN and RIKEN/BNL Research Center** (Group Leaders: H. En'yo, G. Bunce)

Funds spin physics equipment; develops polarimetry; organizes spin workshops; supports young physicists.

- **STAR Spin Physics Working Group** (Conveners: L. Bland, G. Eppley)
- **PHENIX Spin Physics Working Group** (Conveners: Y. Goto, K. Barish)
- **pp2pp Experiment** (Spokesman: W. Guryn)
- **BNL Groups: RHIC Spin Group** (Group Leader: G. Bunce); **RBRC/Nuclear Theory**

Develop / exploit spin capability of RHIC; coordinates accelerator / experiment activities; complete measurements; members in STAR, PHENIX and pp2pp experiments.

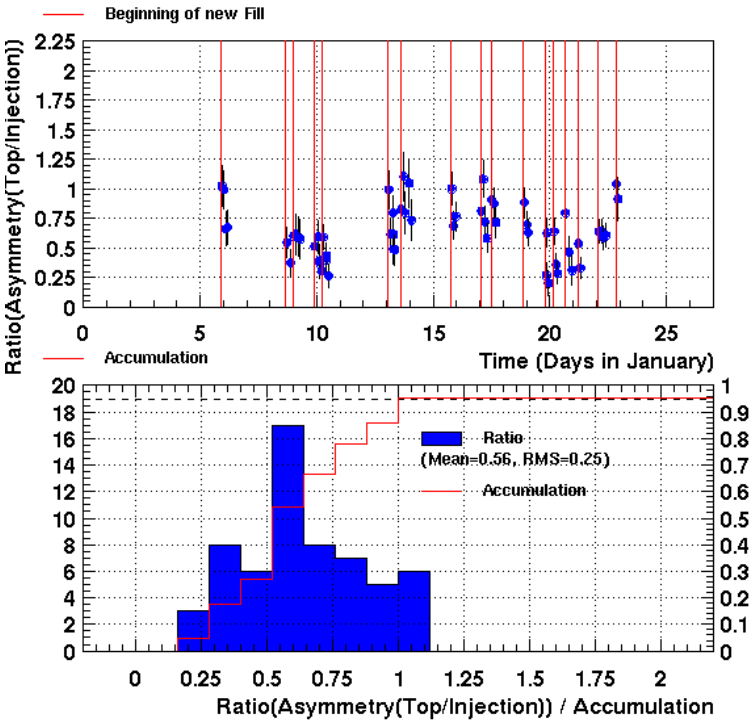
- **Laboratory / University participation**

BRAHMS collaboration, PHENIX collaboration, pp2pp collaboration, STAR collaboration

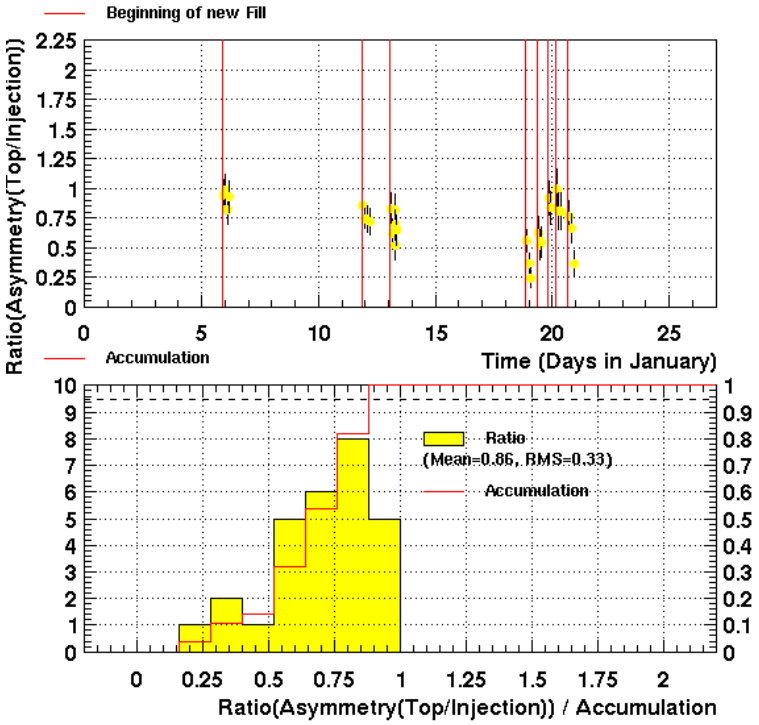
New groups: Cal Tech, Colorado, Illinois, MIT

BROOKHAVEN NATIONAL LABORATORY

Run 2 Progress / Results



Siberian Snakes work to preserve polarization through acceleration and store.



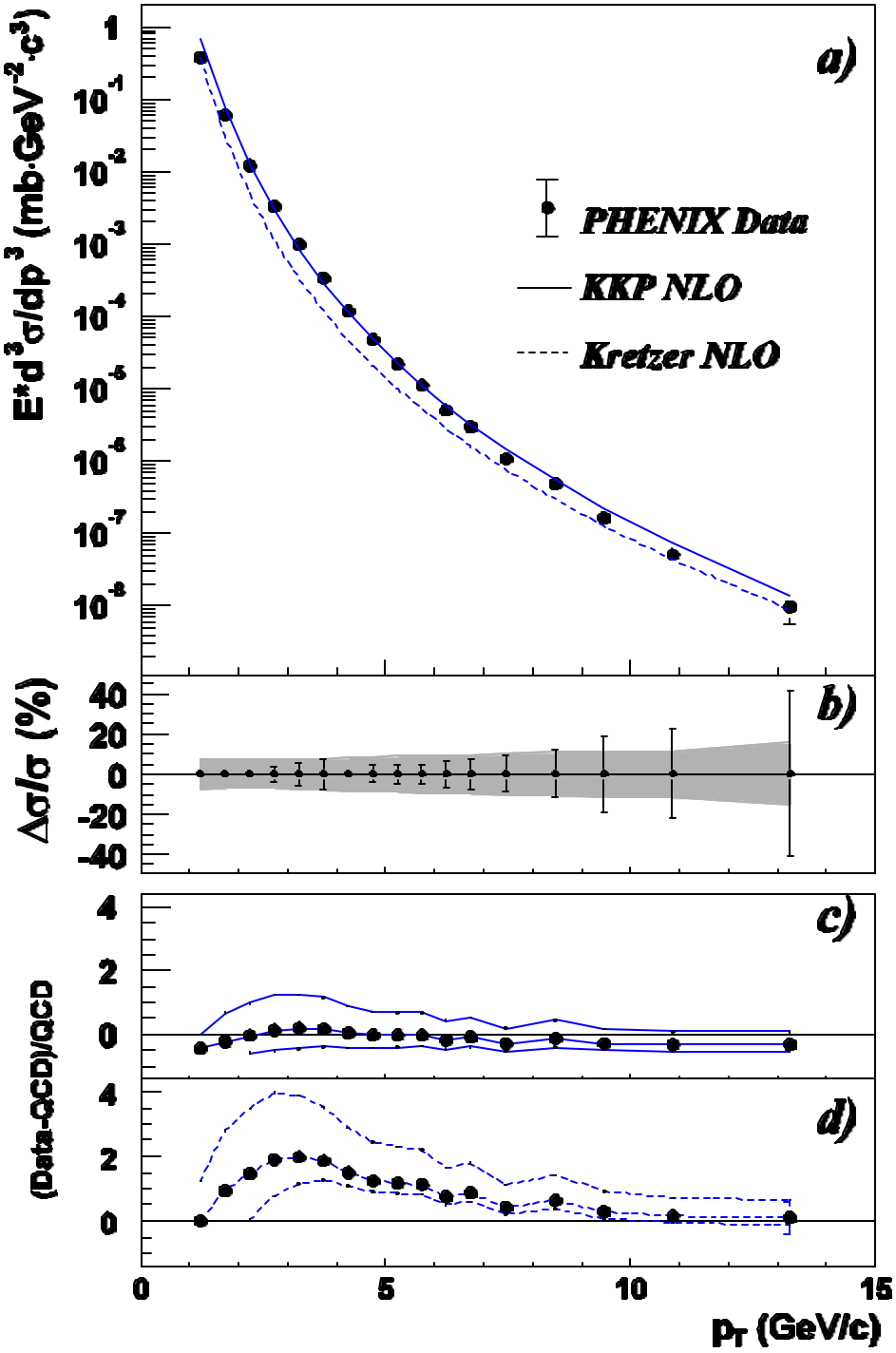
- $\int \mathcal{L}\, dt$ ~350 nb^{-1} and $\langle P_{beam} \rangle$ ~ 18% (Yellow) / 15% (Blue) delivered to experiments. Polarization limited by performance of AGS.
- STAR / PHENIX / pp2pp experiments commissioned for *pp* collisions at $\sqrt{s}$ = 200 GeV.

- Critical *pp* reference measurements for heavy-ion program completed providing important physics results.
- Transverse single-spin measurements completed providing physics results + local polarimeters for spin-rotator tuning in Run 3.

BROOKHAVEN NATIONAL LABORATORY

π^0 Cross Section

- The data covers over 8 order of magnitude
  - –by combining minimum bias trigger and EMCal trigger data
- NLO pQCD calculation is consistent with data
  - –CTEQ5M PDF + KKP FF



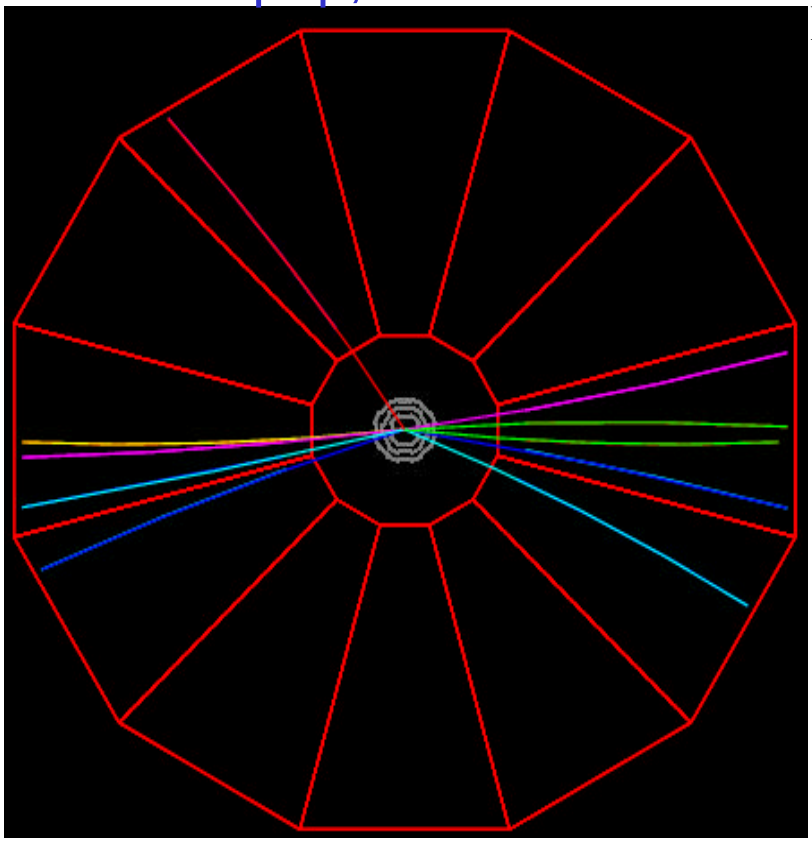
H. Torii, Kyoto University
B. Fox (BNL), SPIN 2002

submitted to PRL, hep-ex/0304038

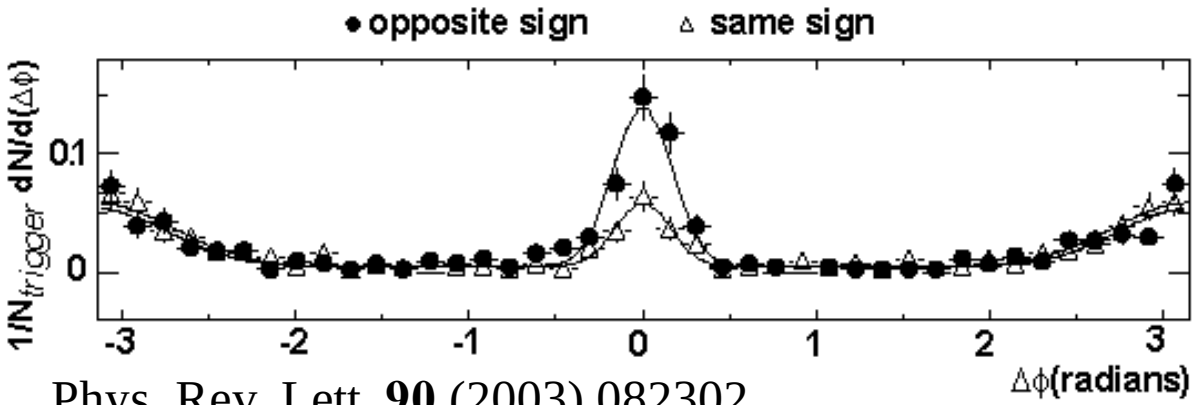
Di-jet Reference for Heavy-Ion Physics

(jet physics is central to spin program)

STAR p+p, √s = 200 GeV



Hadronic high-p_T azimuthal correlations in *pp* collisions



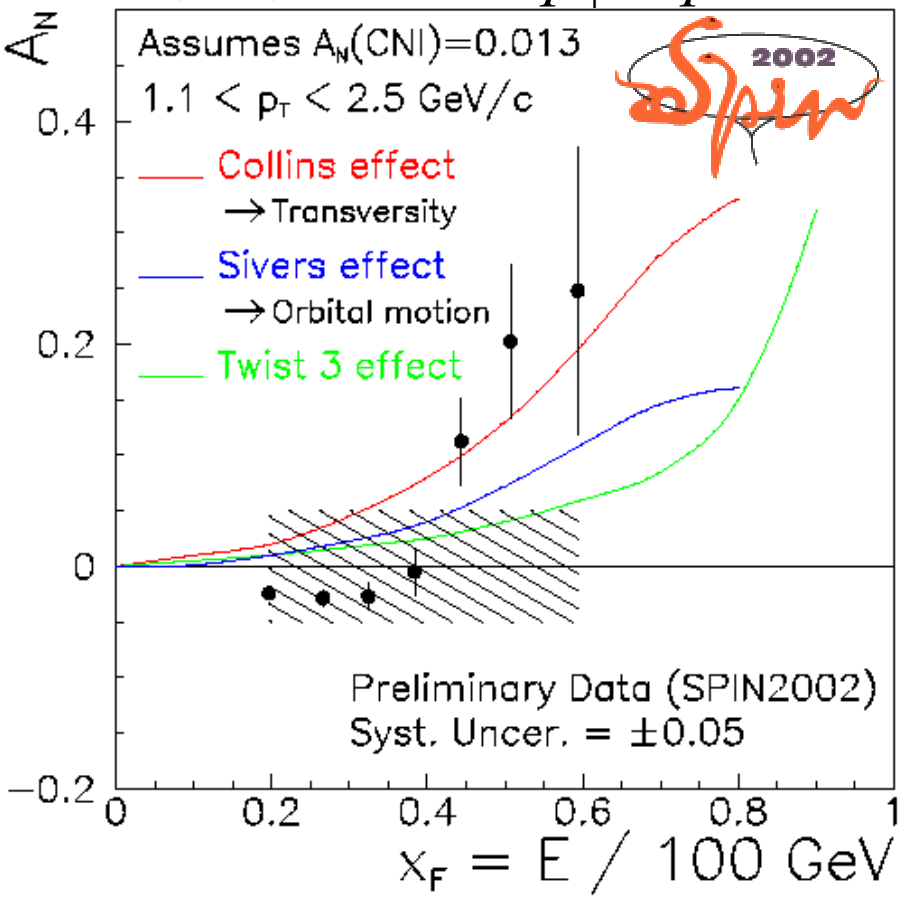
Phys. Rev. Lett. **90** (2003) 082302

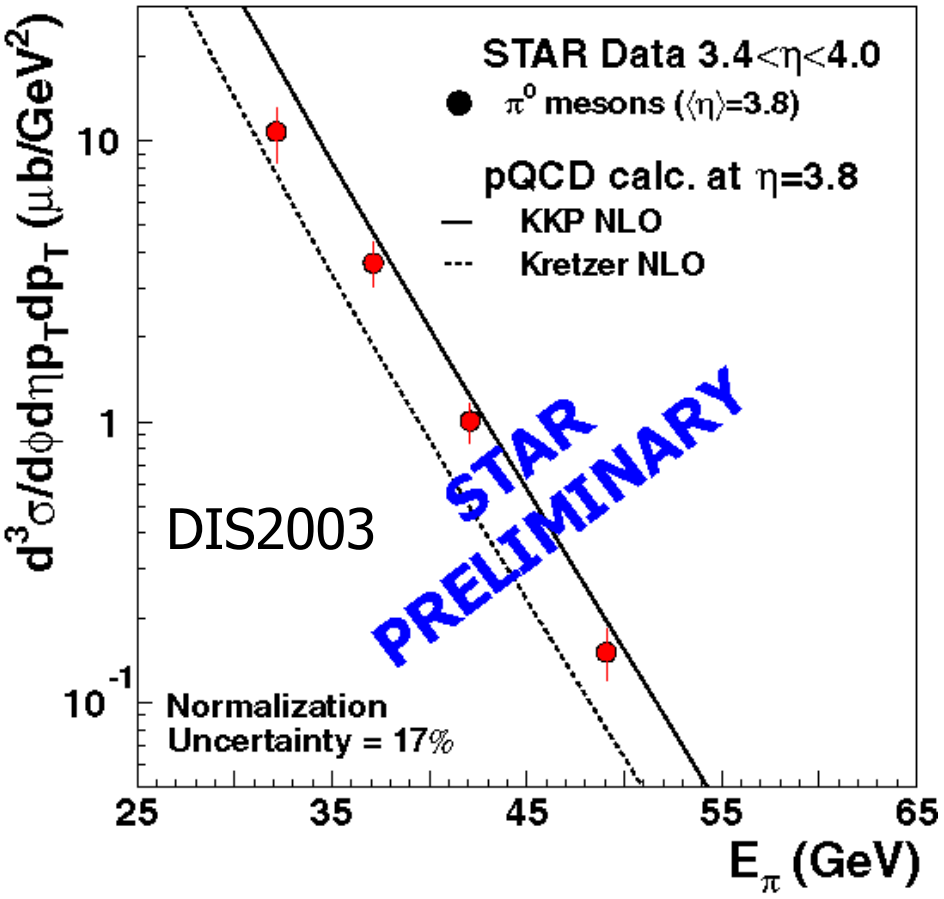
- di-jet events clearly observed in *pp* collisions at $\sqrt{s}$ = 200 GeV.
- di-hadrons serve as di-jet surrogates for heavy-ion collisions.
- clear near-side and away-side di-hadron correlations in *pp* collisions serve as contrast for central AuAu collisions where away-side correlations are strongly suppressed.

STAR

STAR-Spin Results from Run 2

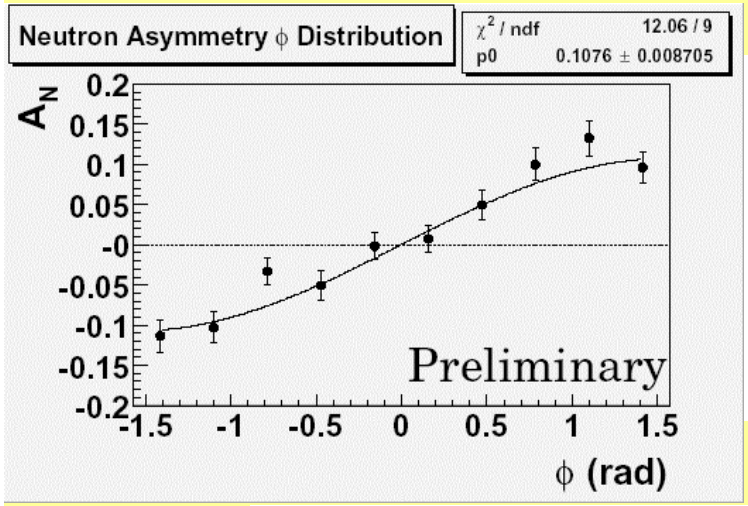
$p_{\uparrow} + p \rightarrow \pi^0 + X$, $\sqrt{s} = 200$ GeV



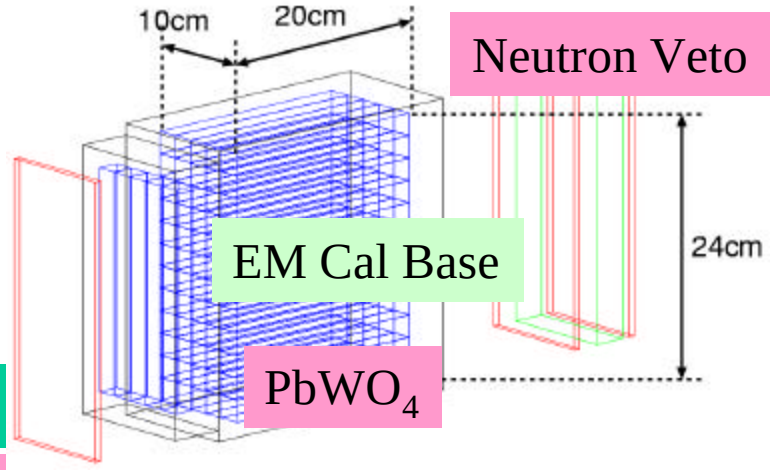


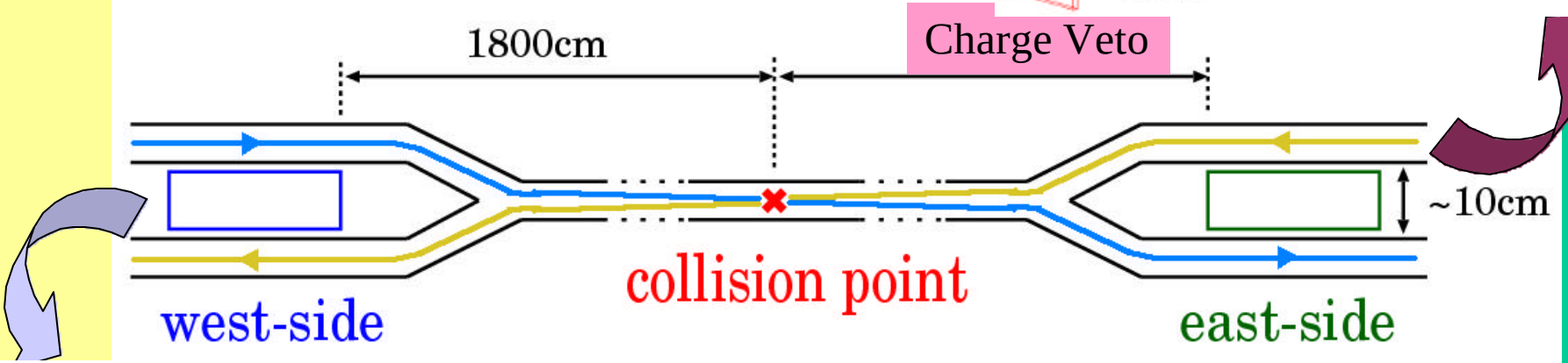
- Measured cross sections consistent with pQCD calculations
- Large spin effects observed for $\sqrt{s} = 200$ GeV pp collisions

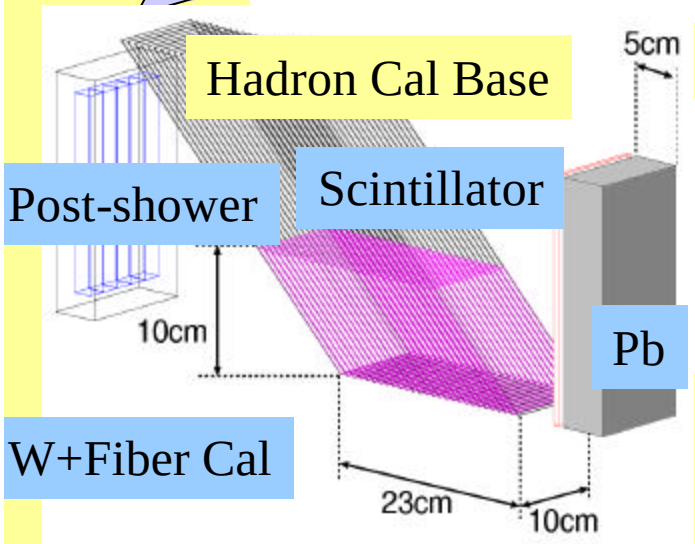
Status: final analysis complete / paper in preparation



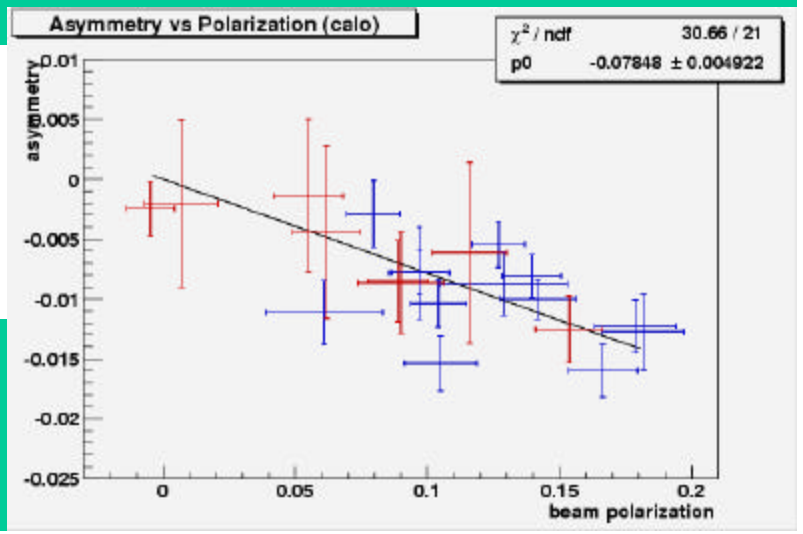
Analyzing Power for Forward Neutron Production at √s = 200 GeV (Run 2 Result)







Results from run 2 are basis for PHENIX local polarimeter used in run 3



Y. Fukao (Kyoto)
SPIN 2002

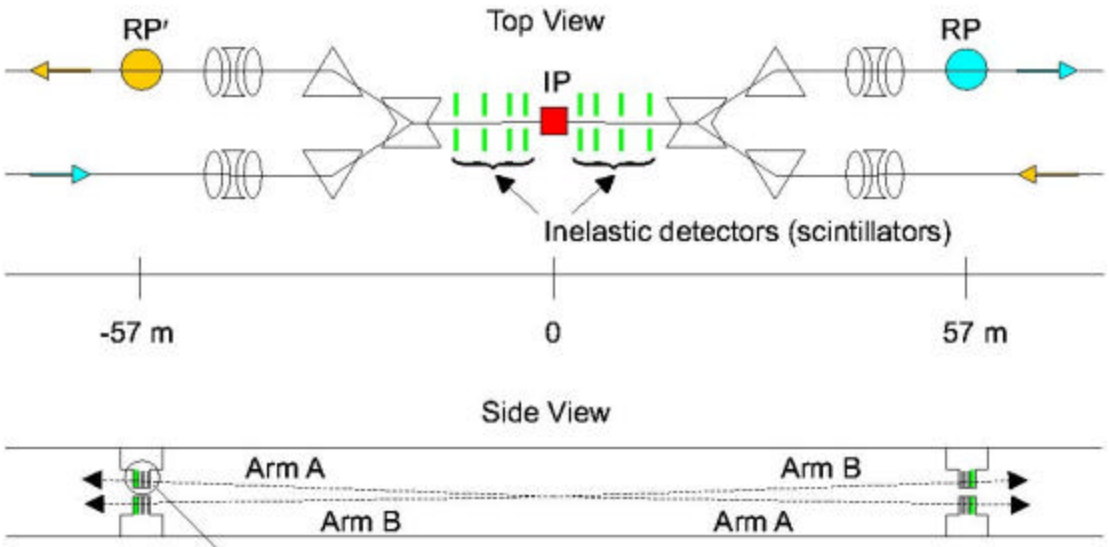
pp2pp
Run-2 Results

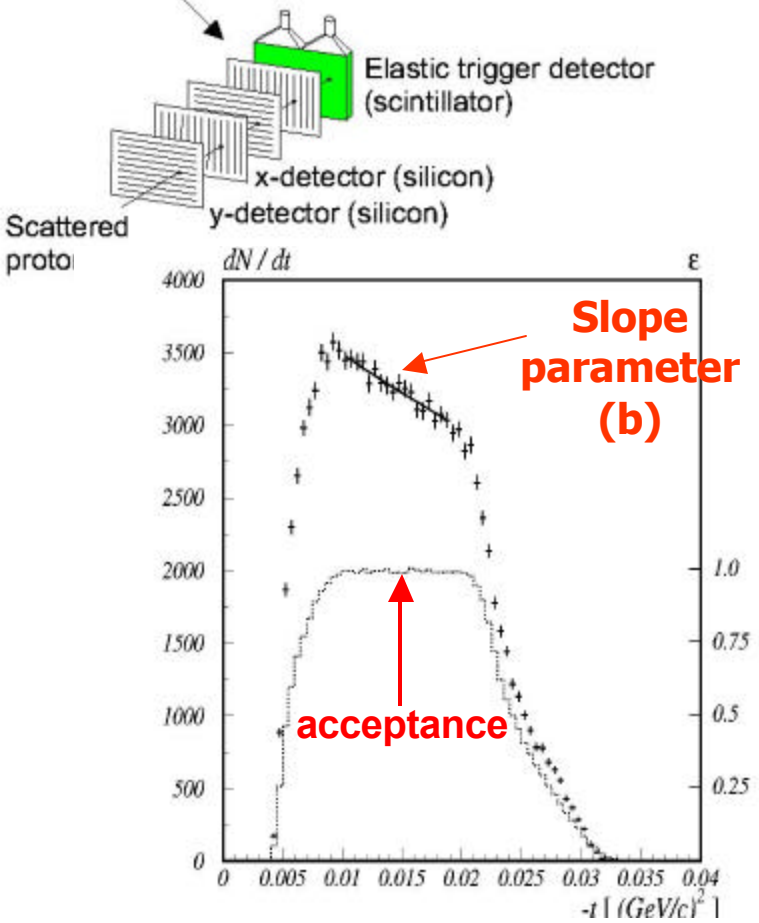
Measurement of small-angle $p_{\uparrow}p_{\uparrow}$ elastic scattering at

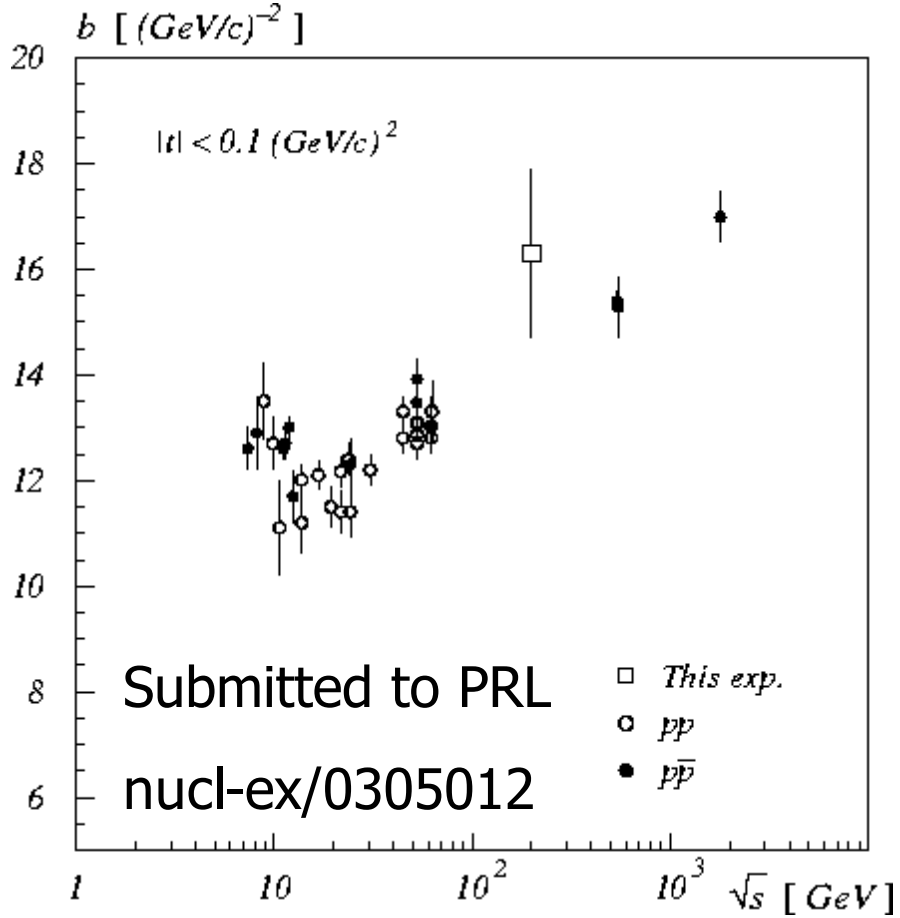
$50 \leq \sqrt{s} \leq 500$ GeV;

$4 \times 10^{-4} \leq |t| \leq 1.3$ (GeV/c)^2

using Si strip detectors in Roman Pots above and below the beam.







Submitted to PRL

nucl-ex/0305012

Run 3 Plans / Performance / Progress

Commissioning…

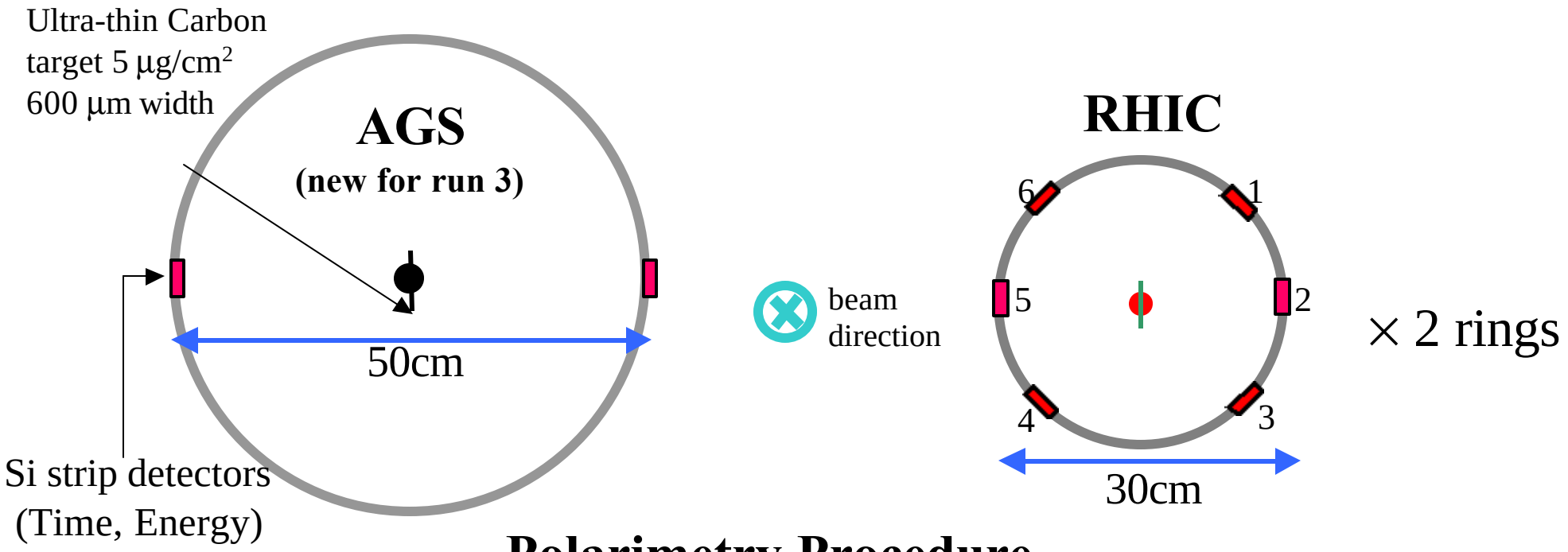
- Fast polarimeter for AGS / polarization measurements along the ramp.
- high-luminosity (β^*=1 m) optics at PHENIX and STAR interaction regions.
- tuning RHIC spin rotators $\Rightarrow$ producing longitudinal polarization at PHENIX and STAR / measuring residual transverse polarization components with local polarimeters.

Physics measurements…

- transverse single spin asymmetries for $p_{\uparrow}+p \rightarrow \pi^0+X$ at $\sqrt{s}$=200 GeV to discriminate underlying dynamics.
- probing ΔG via first measurements of A_{LL} for hadrons and jets produced at mid-rapidity.

BROOKHAVEN NATIONAL LABORATORY

CNI Polarimeters



Polarimetry Procedure

- Measure recoil carbons from $p^{-}C \rightarrow p^{-}C$ elastic scattering

- Exploit analyzing power, $A_N \approx 0.01$, originating from anomalous magnetic moment of proton. Calibration of A_N required.

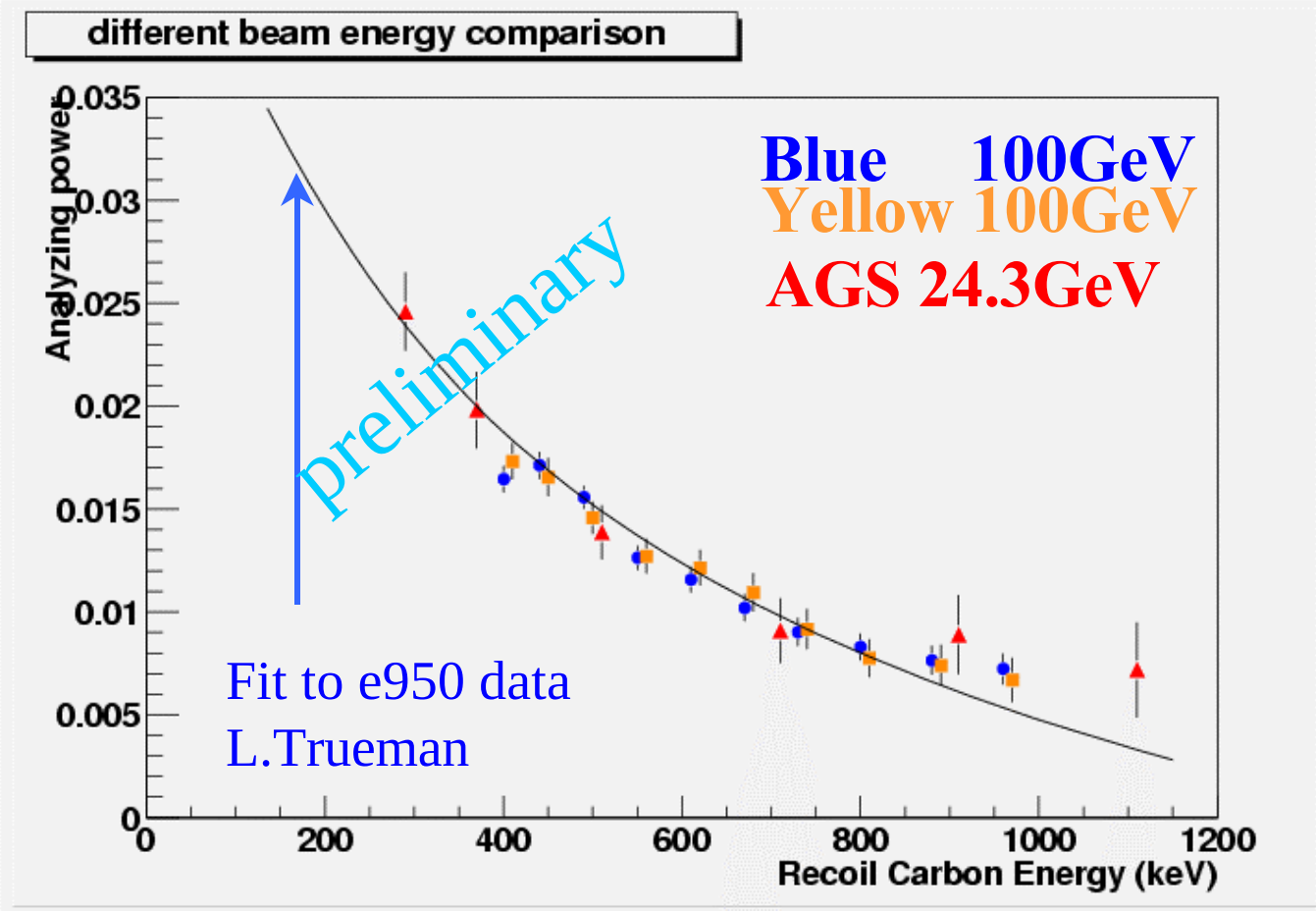
- Measure left/right (more generally, azimuthal variation) spin-dependent asymmetry

$$\varepsilon_{LR} = \frac{\sqrt{N_{L-}N_{R-}} - \sqrt{N_{L-}N_{R-}}}{\sqrt{N_{L-}N_{R-}} + \sqrt{N_{L-}N_{R-}}} \quad , \quad P_{beam} = \frac{\varepsilon_{LR}}{A_N}$$

BROOKHAVEN NATIONAL LABORATORY

-t Dependence of CNI Analyzing Power

(Run 3 Result)

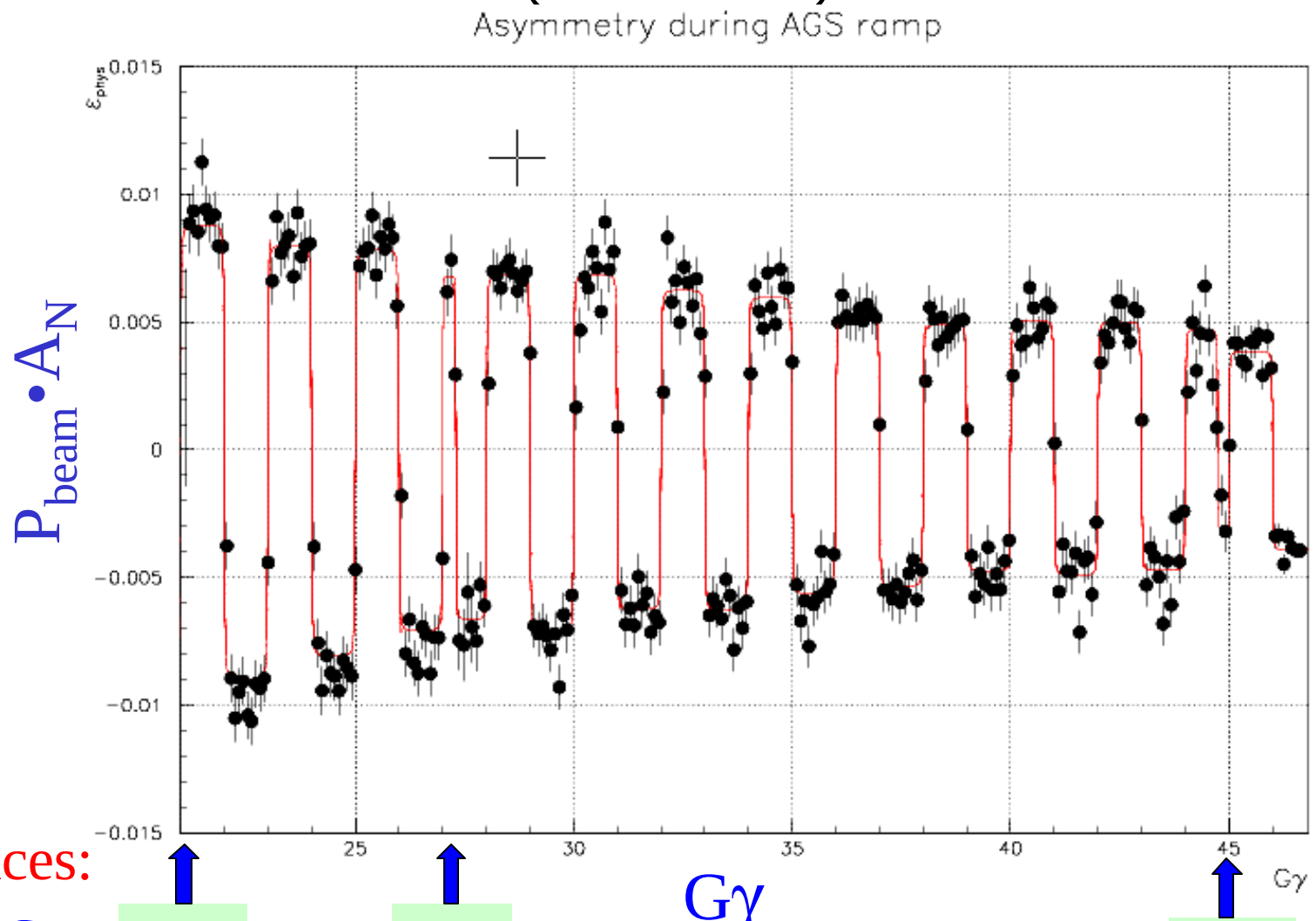


- Normalization of the data points are assumed
- A_N has a very small dependence on beam energy

BROOKHAVEN NATIONAL LABORATORY

Polarization Measurements Along AGS Ramp

(Run 3 Result)



resonances:

intrinsic: Gγ = 12+ν, 36-ν

imperfection: Gγ = n

36+ν

BROOKHAVEN NATIONAL LABORATORY

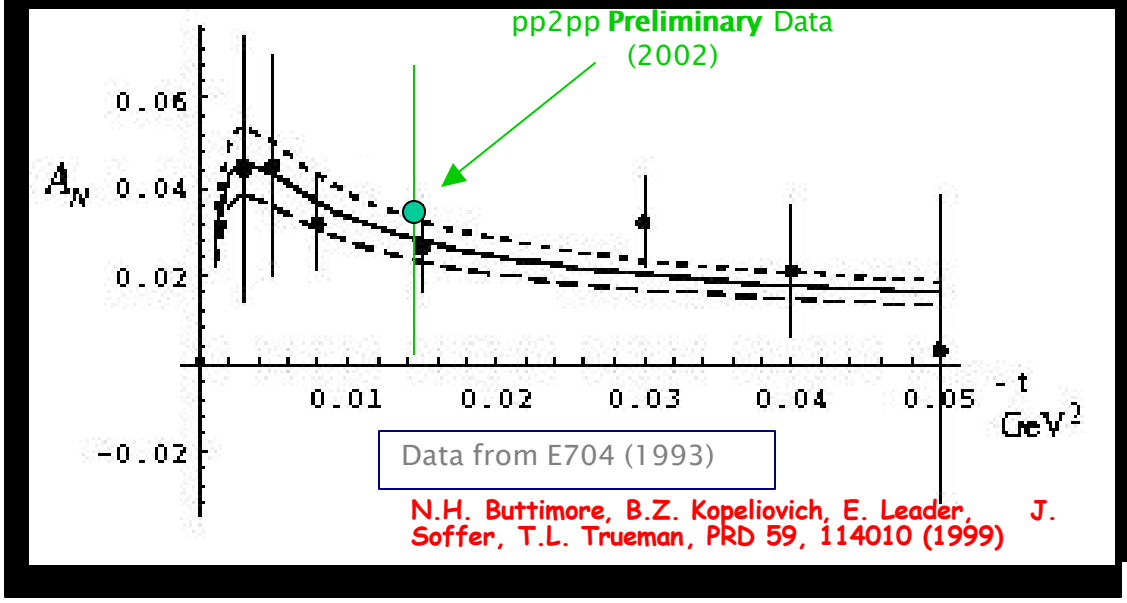
pp2pp

Single spin asymmetry A_N arises in CNI region from interference of hadronic non-flip amplitude with electromagnetic spin-flip amplitude

Measure dependence on |t | and on azimuthal scattering angle f

Deviation of |t |-dependence from calculation with above assumption will give access to hadronic spin-flip contribution to amplitude

Also measure double spin asymmetry A_{NN} to probe possible contribution of Odderon exchange to dominant Pomeron exchange in same |t | region



Review of achievements of runs in 2002 and 2003

	2002	2003
p^+ intensity / beam	$0.5 \cdot 10^{12}$	$1.9 \cdot 10^{12}$
p^+ polarization	0.24	0.37
Beam tune b*	10 m	10 m
Beam momentum	100 GeV	100 GeV
Elastic events	300,000	3 Million

Expected statistical errors (on single data point)

dA_N	0.025	0.005
db	1.60	0.35

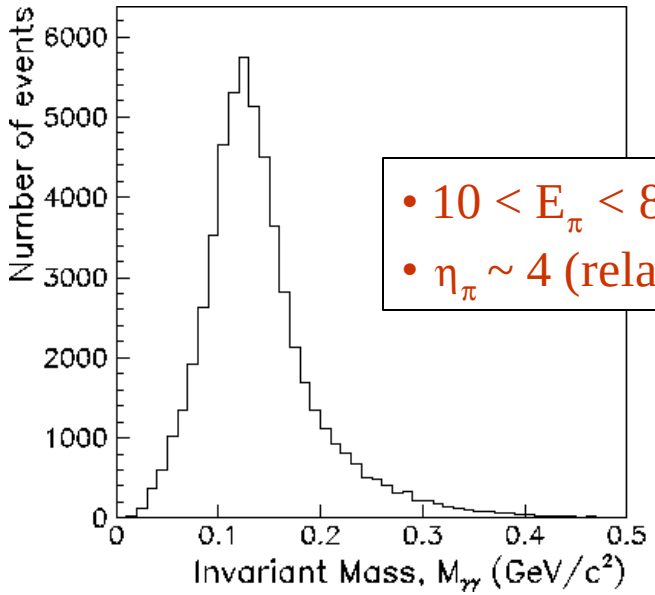
Improvement of systematic error due to

- Measurement of local angle with Roman Pot station set added in 2003
- Beam tune measurement

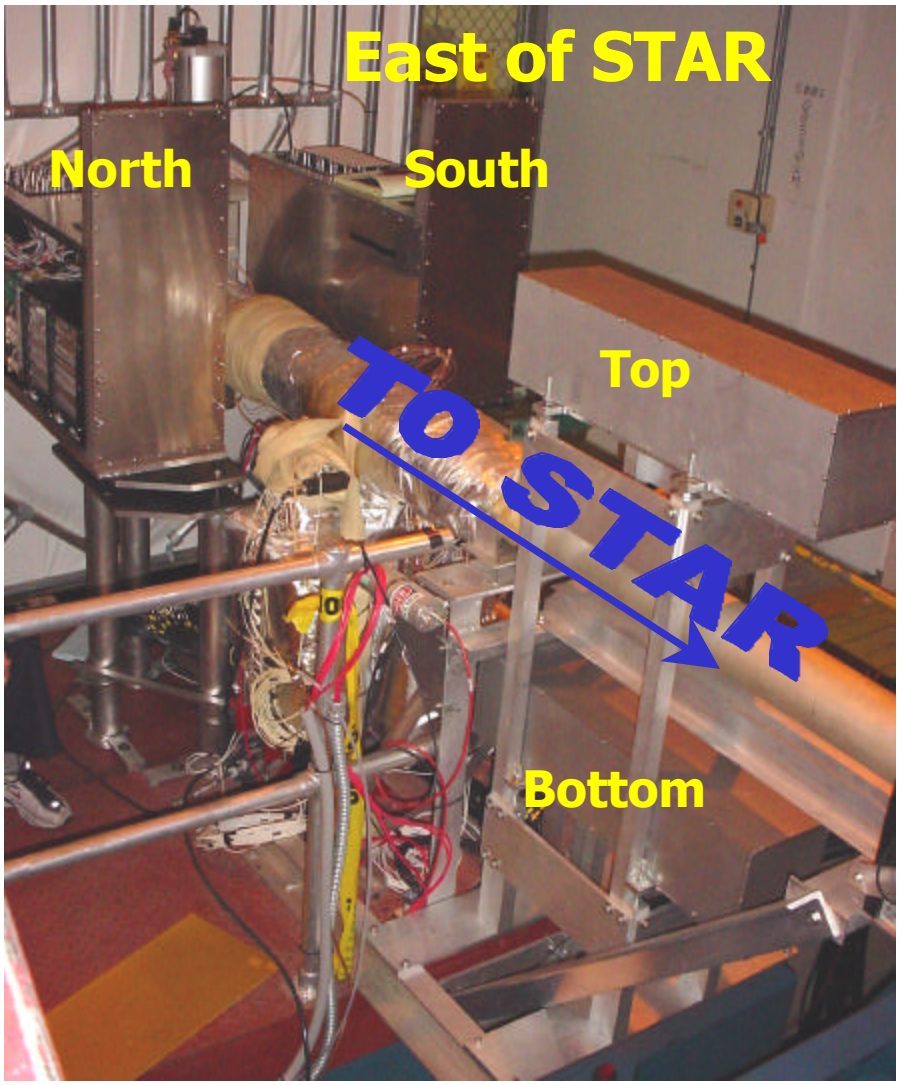
STAR Forward Pion Detector

(Construction for Run 3)

$d+Au \rightarrow \pi^0+X$, $\sqrt{s_{NN}} = 200$ GeV



- $10 < E_\pi < 80$ GeV
- $\eta_\pi \sim 4$ (relative to d)

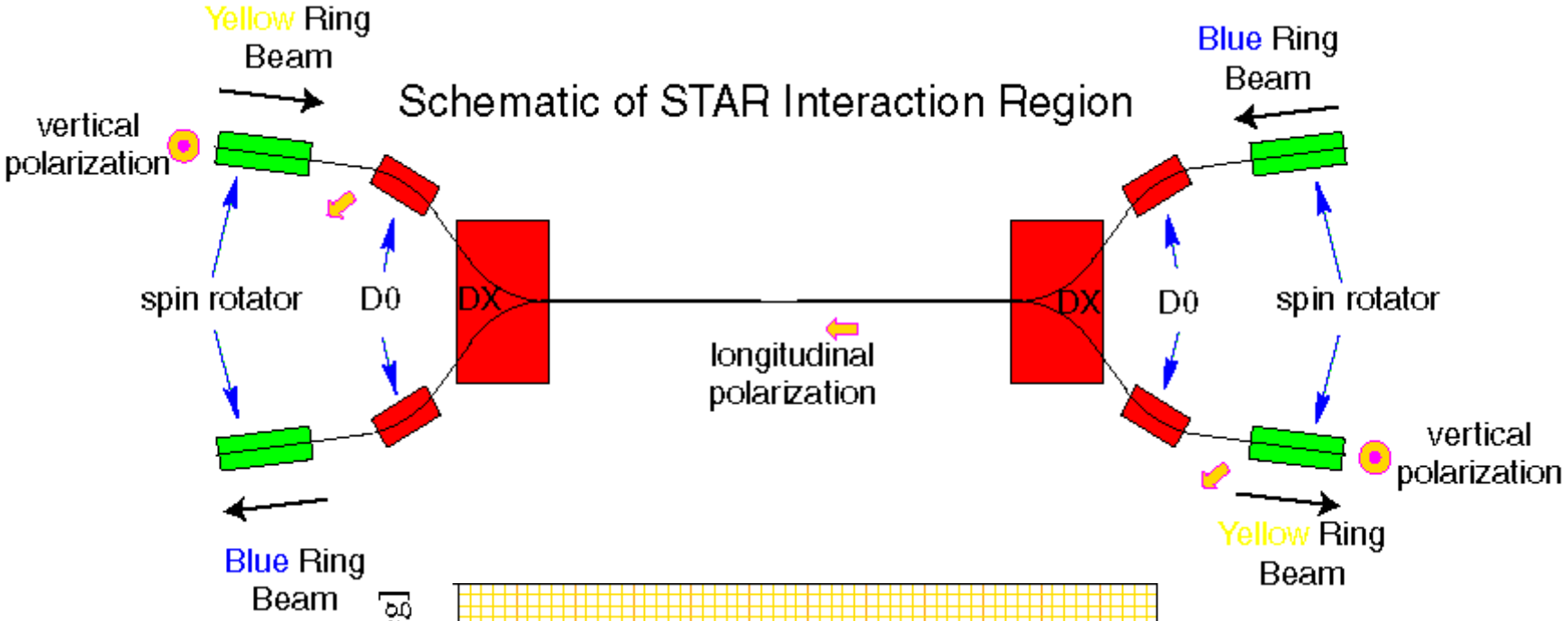


Run 3 Objectives:

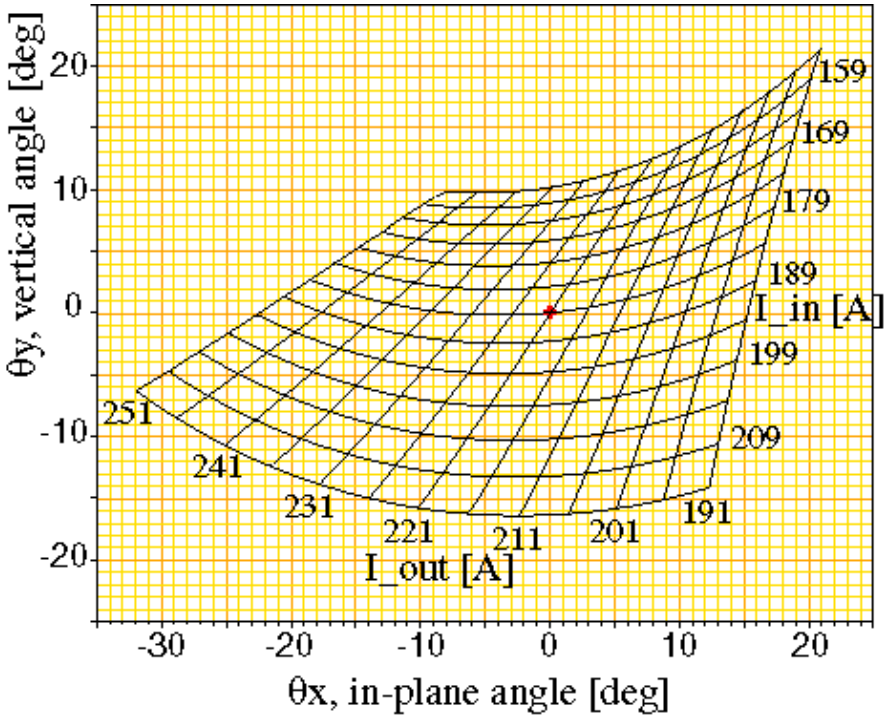
- probe of Color Glass Condensate in d+Au
  - $\Rightarrow p_T$ dependence of large η yield
- improve understanding of dynamical origin of A_N in $p_\uparrow+p \rightarrow \pi^0+X \Rightarrow$
  - Collins effect $\rightarrow$ sensitivity to transversity
  - Sivers effect $\rightarrow$ sensitivity to orbital motion
  - twist-3 effect $\rightarrow$ quark/gluon correlations
- serve as local polarimeter at STAR IR

BNL, Penn State, IHEP-Protvino,
UC Berkeley/SSL, UCLA, ANL

Spin Rotators and Local Polarimetry



Calculations establish a working point and the dependence of transverse polarization components on spin rotator currents.



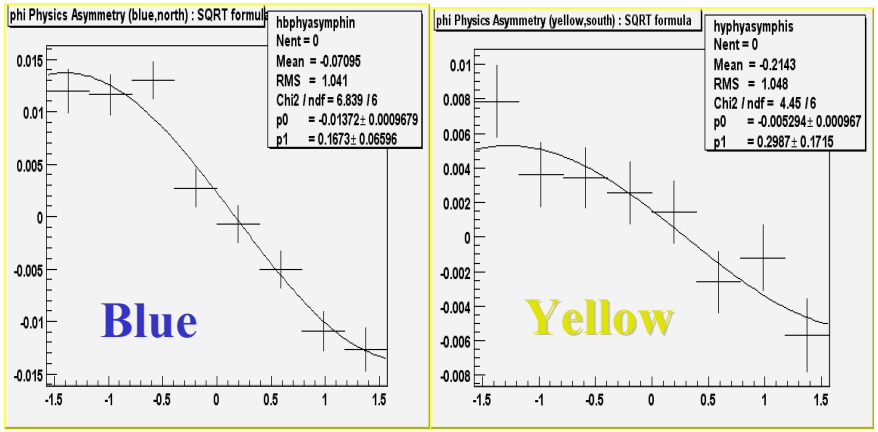
Local polarimeters are needed to measure vertical,radial polarization components at interaction region.

BROOKHAVEN NATIONAL LABORATORY

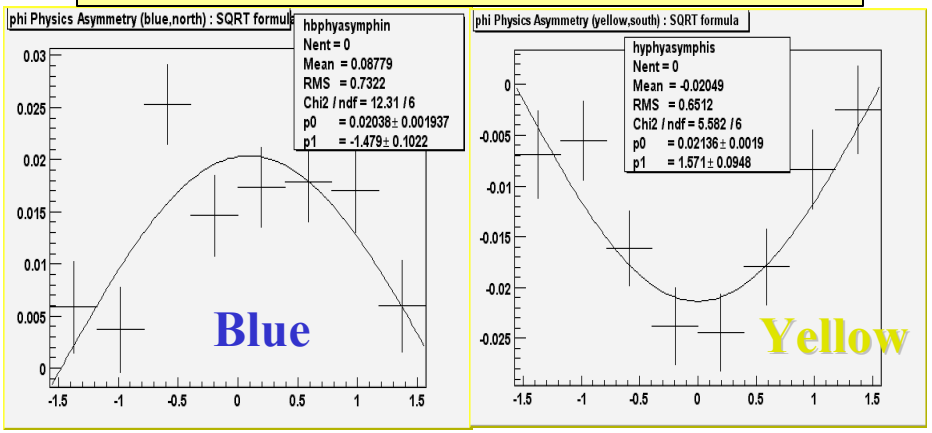
Local Polarimeter at PHENIX

Run-03 Result

Spin Rotators OFF

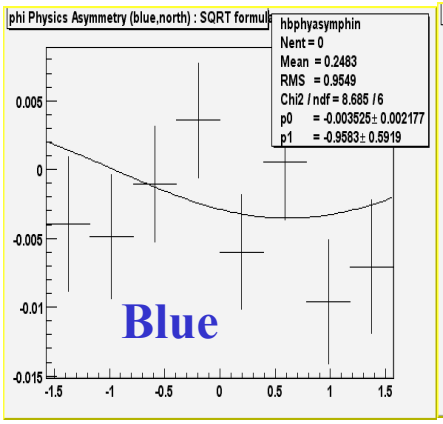


Spin Rotators ON, Current Reversed

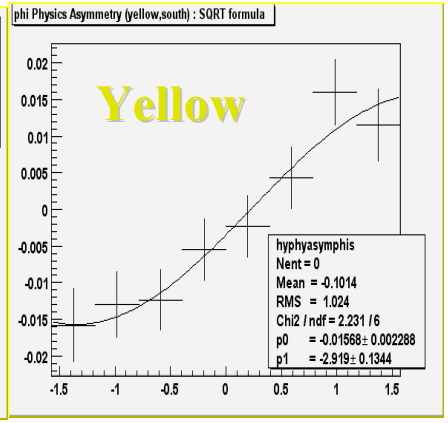


Spin Rotators ON, Almost…

|P|=30%, P_T=0% → P_L=30%)

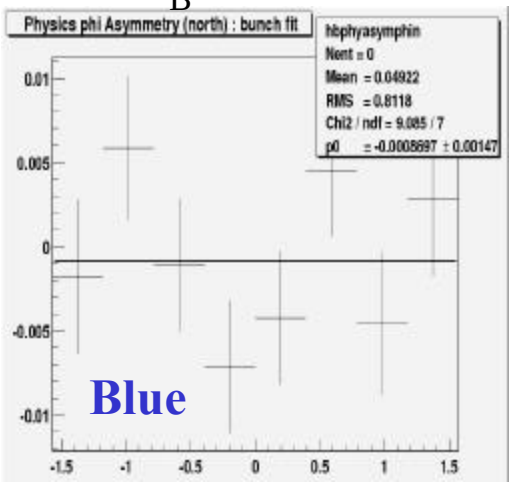


|P|=37%, P_T=24% →P_L=28%)

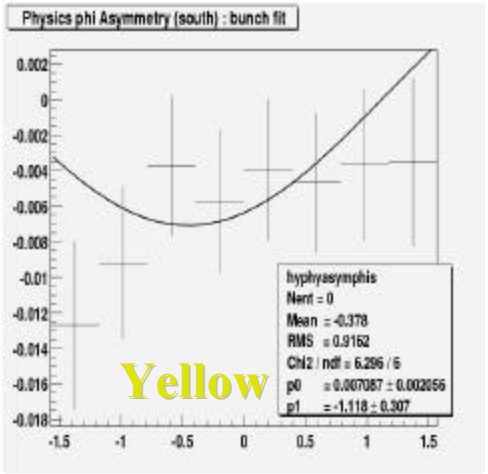


Spin Rotators ON, Correct!

P_B=35.5%

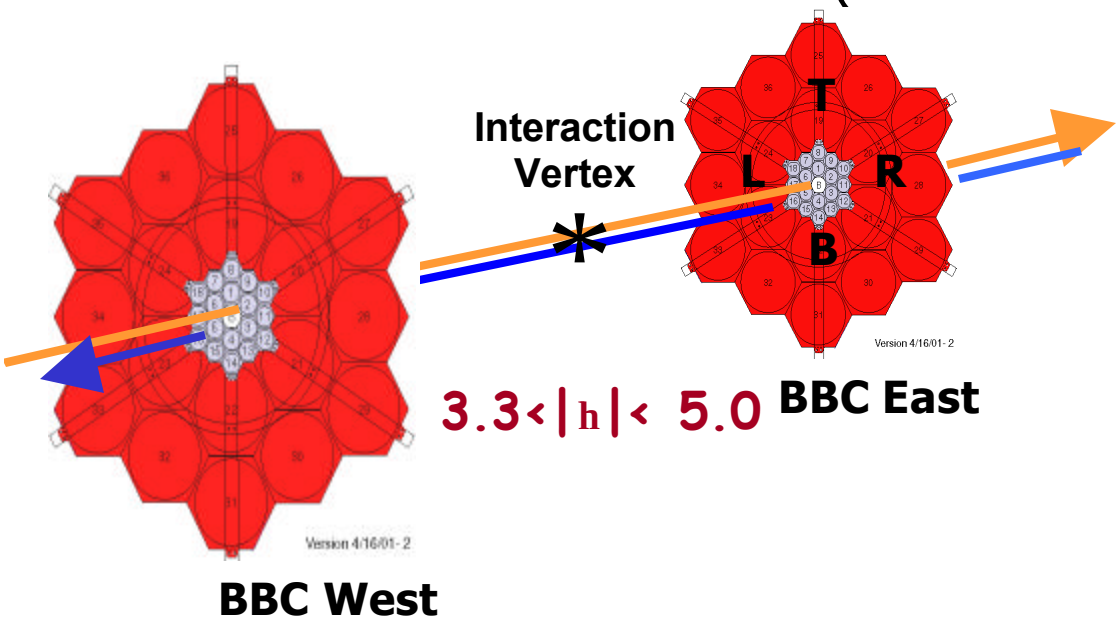


PB=37%



STAR Spin Rotator Magnet Tuning

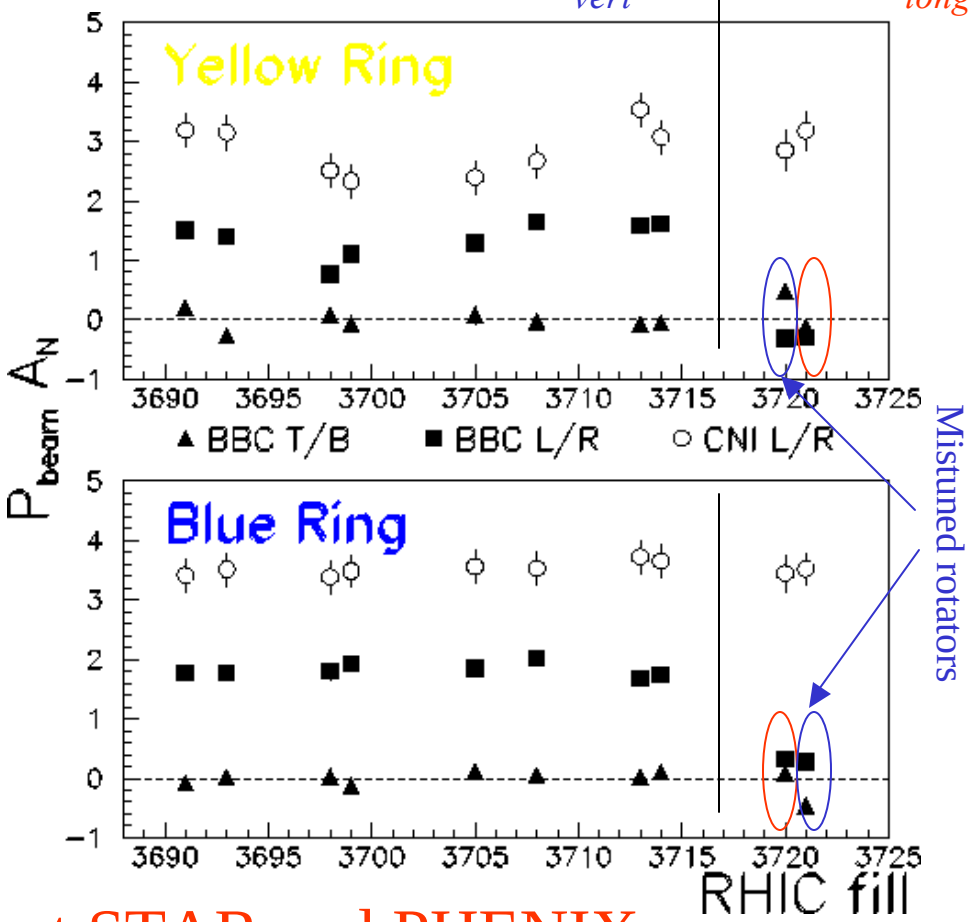
(Run 3 Result)



• *RHIC polarimeter* (CNI) establishes polarization *magnitude.*

• *Local polarimeter* (BBC) establishes polarization *direction* at STAR.

STAR spin rotator: OFF ⇒ P_{vert} ← → ON ⇒ P_{long}



• use segmentation of inner tiles of BBC as a *Local Polarimeter* monitoring *pp* collisions.

• Rotators OFF ⇒ BBC L/R spin asymmetries comparable to RHIC polarimeter (CNI).

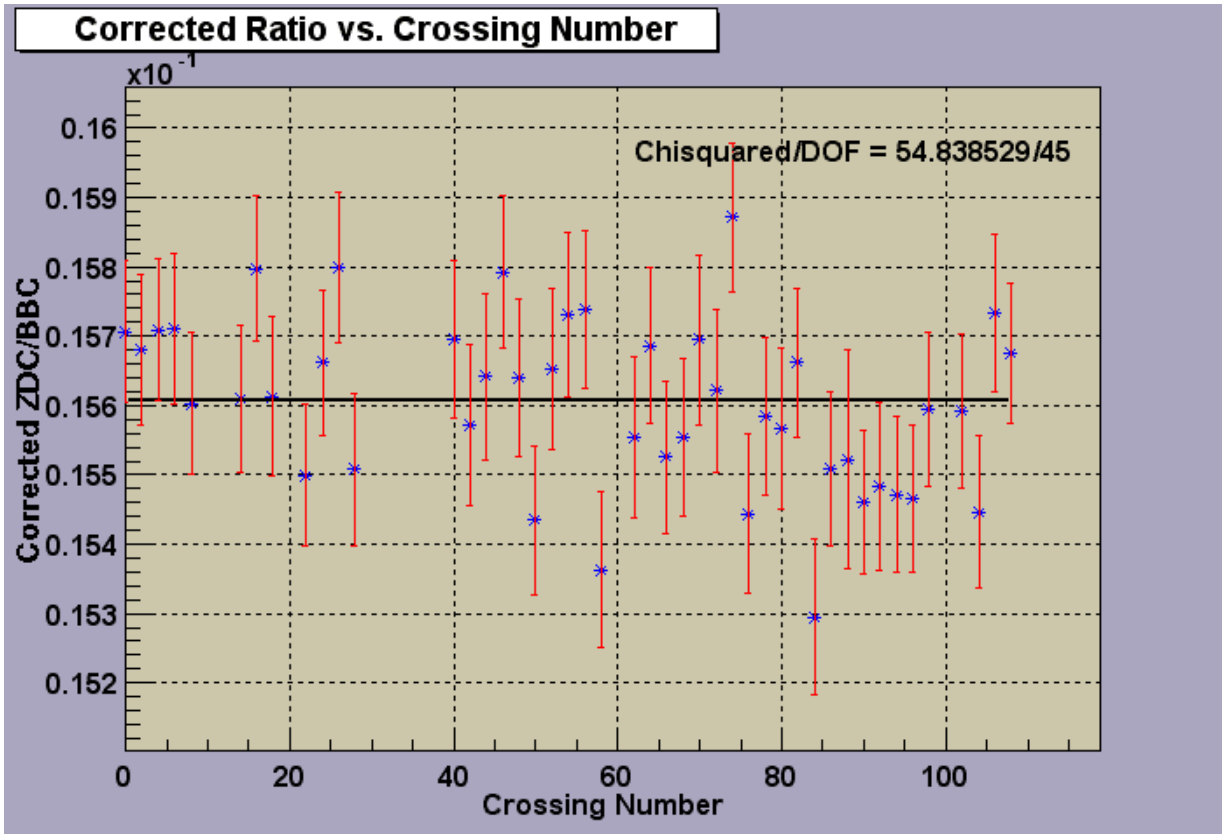
• Rotators ON ⇒ adjust rotator currents to minimize BBC L/R and T/B spin asymmetries.

⇒ Longitudinal Polarization at STAR and PHENIX

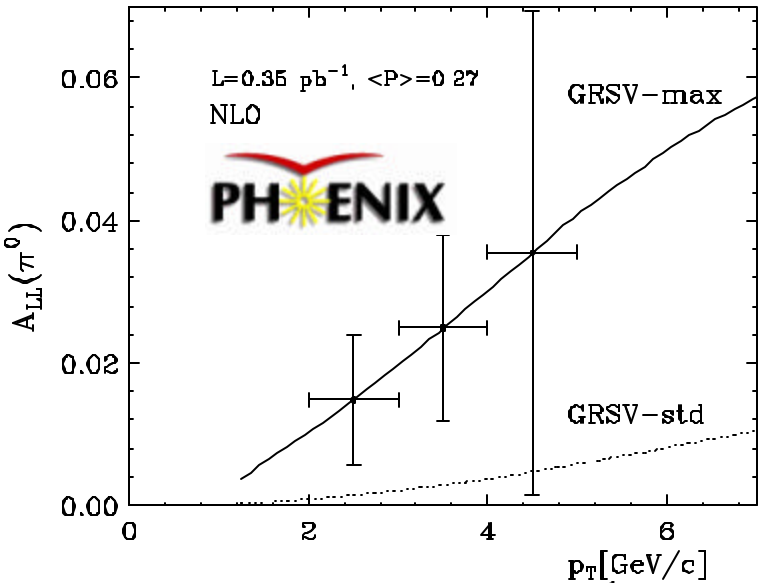
Limit on Relative Luminosity Measurement
(Run 3 Result)

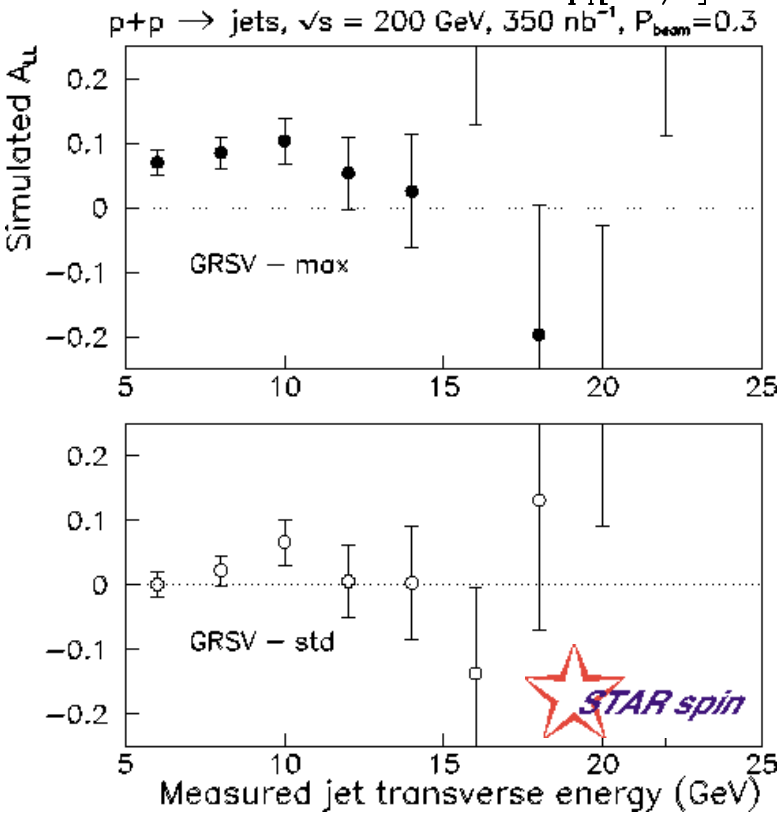
- After correction for (measured) vertex width, the ratio of counts in the ZDC and BBC is consistent with a constant up to our level of statistics
- This means that if we apply correction for vertex width the precision on R goes from:
  0.11% → 0.06%

(syst. limited) (stat. limited)



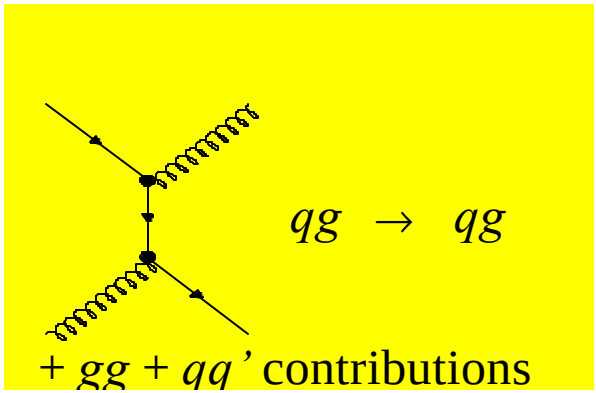
Projections for Sensitivity to ΔG from Run 3

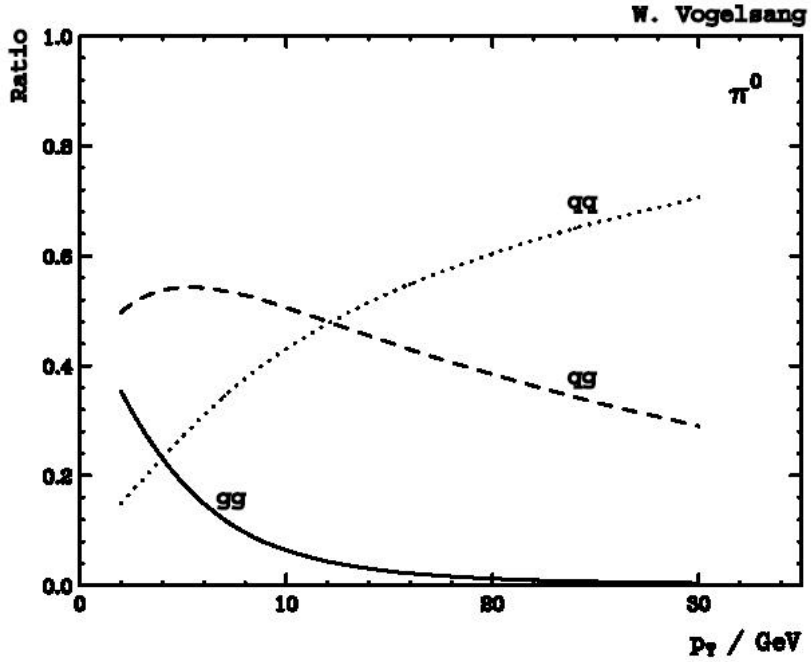




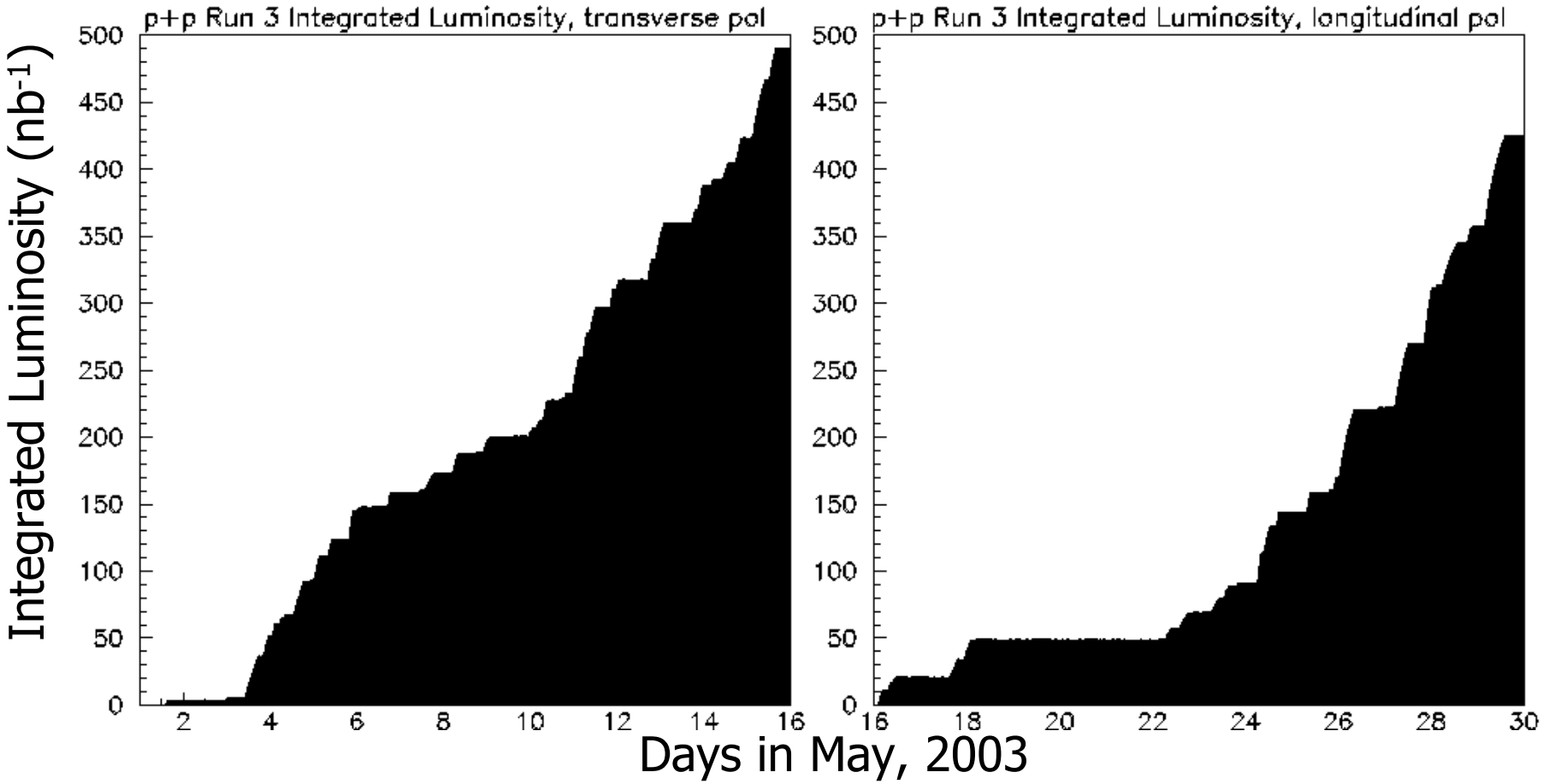
Longitudinal spin asymmetry (A_{LL}) for mid-rapidity jet production

⇒ first measurements sensitive to gluon polarization





p+p Integrated Luminosity for Run 3 Delivered to STAR IR

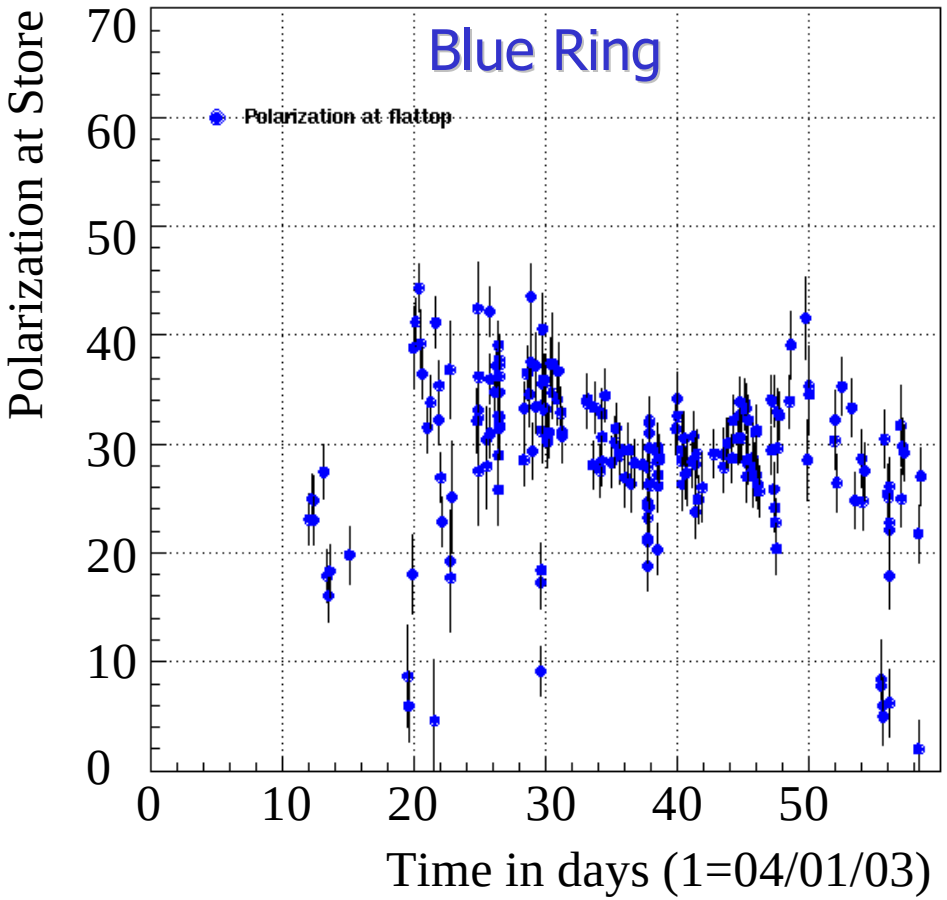


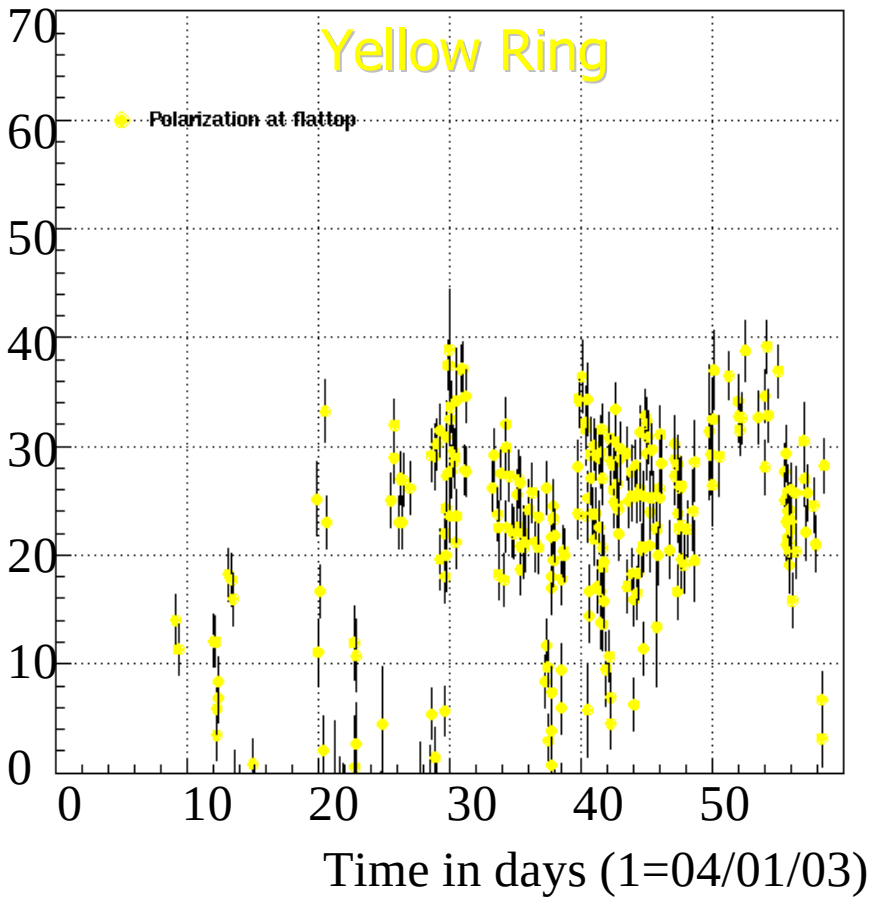
Integrated luminosity from STAR BBC, selected on signal:background > 3

Delivered luminosity limited by 'beam-beam tune shifts' but should be adequate to accomplish physics goals from Run 3.

BROOKHAVEN NATIONAL LABORATORY

RHIC Polarization at store for Run 3





- RHIC polarization improved by factor of ~2 compared to run 2
- Yellow ring affected by problem with snake magnet

(failure of inner helical windings of Yellow ring magnet).

BROOKHAVEN NATIONAL LABORATORY

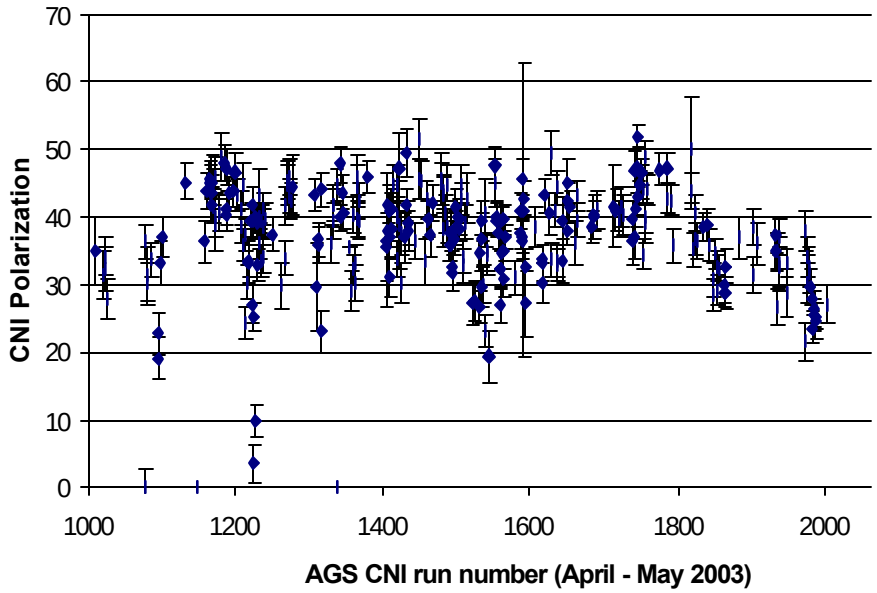
Run 3 Polarized pp Summary

Accomplishments…

- x2 improvement in polarization from AGS relative to run 2.
- commissioning of fast CNI polarimeter for AGS and first measurements along energy ramp.
- transverse single spin measurements:
  - STAR Forward π^0 Detector: $p_\uparrow + p \rightarrow \pi^0 + X$
  - pp2pp: $p_\uparrow p$ elastics at small |t|
- successful commissioning of spin rotator magnets and local polarimeters

$\Rightarrow$ longitudinal polarization at PHENIX and STAR

- determine that spin-dependent relative luminosity is not limiting systematic error for A_{LL}
- first measurements of A_{LL} for mid-rapidity hadron,jet production at STAR and PHENIX



BROOKHAVEN NATIONAL LABORATORY

Issues for Polarized pp Running

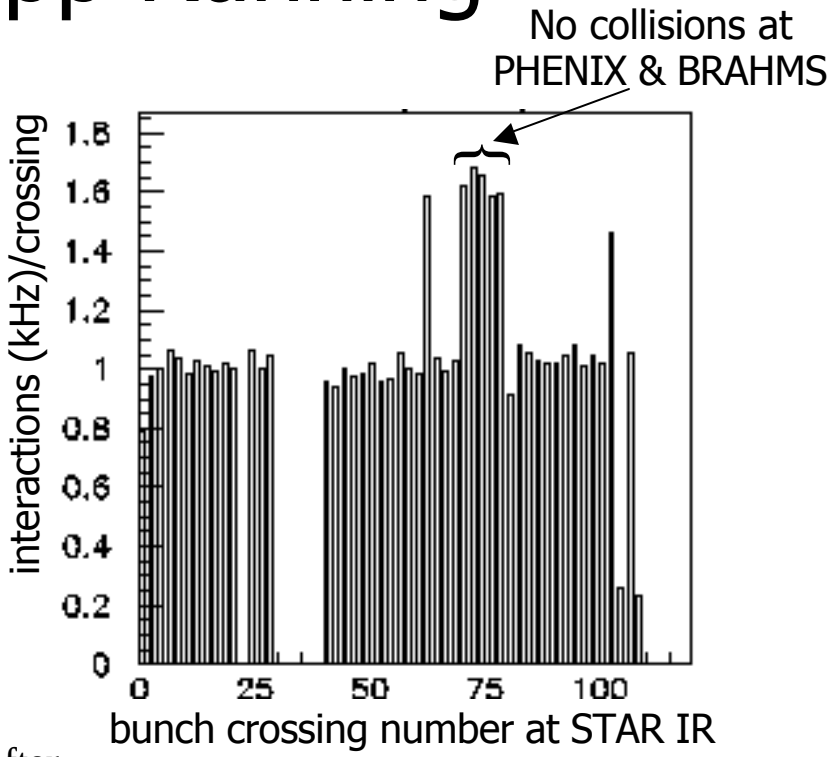
1) Peak and average luminosity smaller than required (20 $\mu b^{-1}s^{-1} \Rightarrow$ ~50 pb^{-1}/week at $\sqrt{s}$=500 GeV) for measuring spin asymmetries for γ,$W^{\pm}$ production.

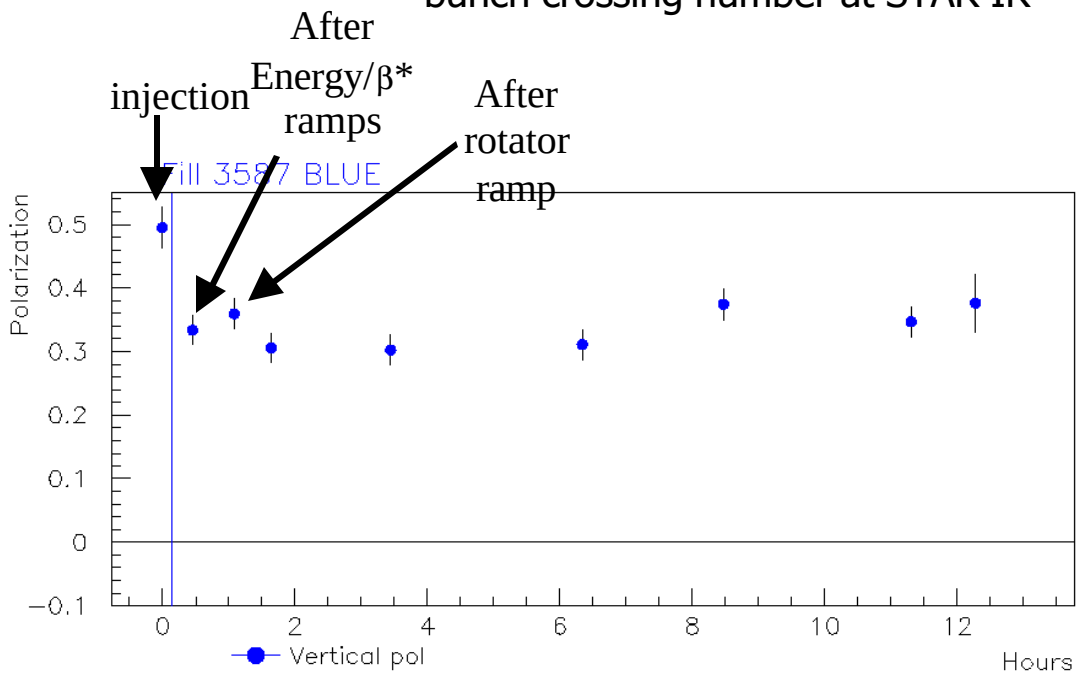
2) Evidence that bunches with fewer interactions produce larger luminosity $\rightarrow$ onset of beam-beam tune shift/spread effects.

3) Evidence of polarization loss in RHIC.

4) β*=1m optics produces significant background at interaction regions.

5) Adequate time for commissioning/luminosity development in upcoming runs.



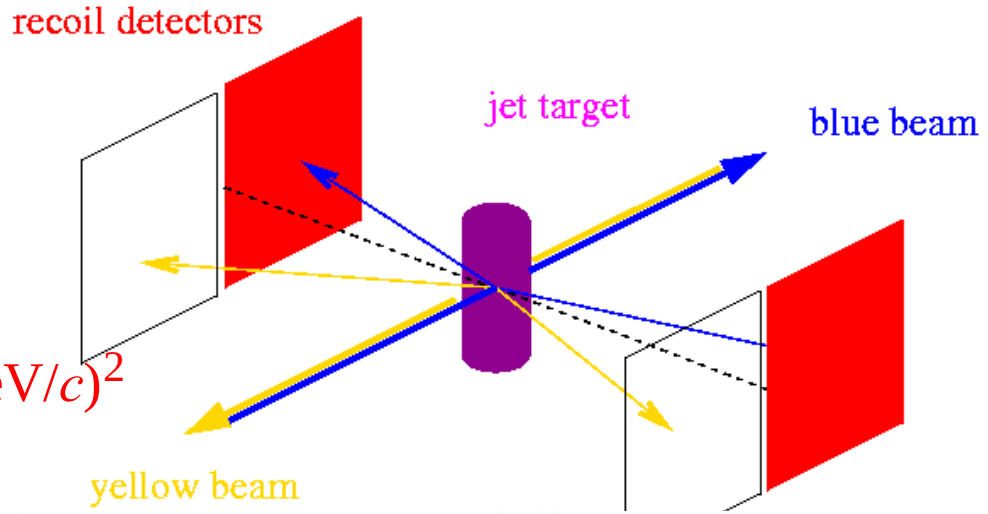


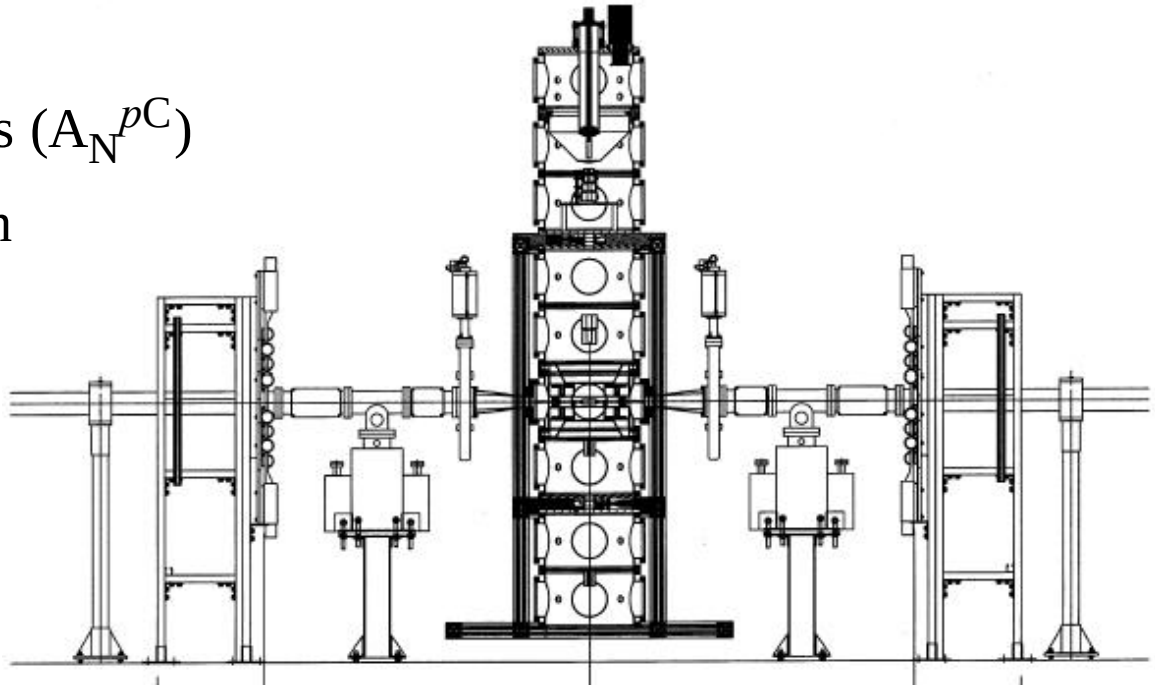
BROOKHAVEN NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

p_p, $pp\_$ and $p\_p\_$ with a Polarized Gas Jet Target

- Polarized Hydrogen Gas Jet Target
  thickness of 5×10^{11} p/cm^2
  polarization > 90%
- Silicon recoil detectors
- Rate: 125 Hz for $0.001 < |t| < 0.02$ (GeV/c)^2
- Measure A_N^{pp} in pp elastic scattering in the CNI region to a 3% accuracy
- Transfer A_N^{pp} to the pC polarimeters (A_N^{pC})
- Expected accuracy on P_B of 6% with "calibrated" pC CNI polarimeters
- Install for the '04 run
- Initially measure P_{beam} to 10%





BROOKHAVEN NATIONAL LABORATORY

The Polarized Jet Target

Electronics racks

Vac. gauges monitors

Turbo pump controllers

Dissociator RF systems

Dissociator stage

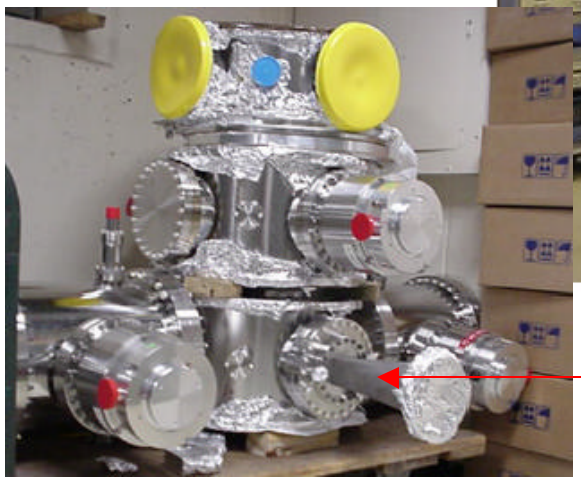
Baffle location

Sextupoles 1-4

Sextupoles 5-6

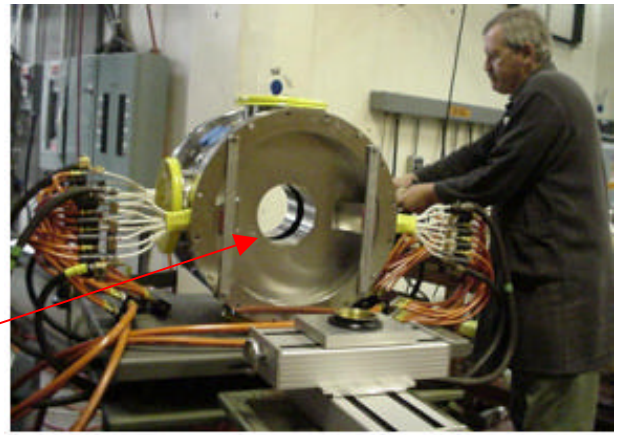
Profile measurement

BRP vacuum vessel

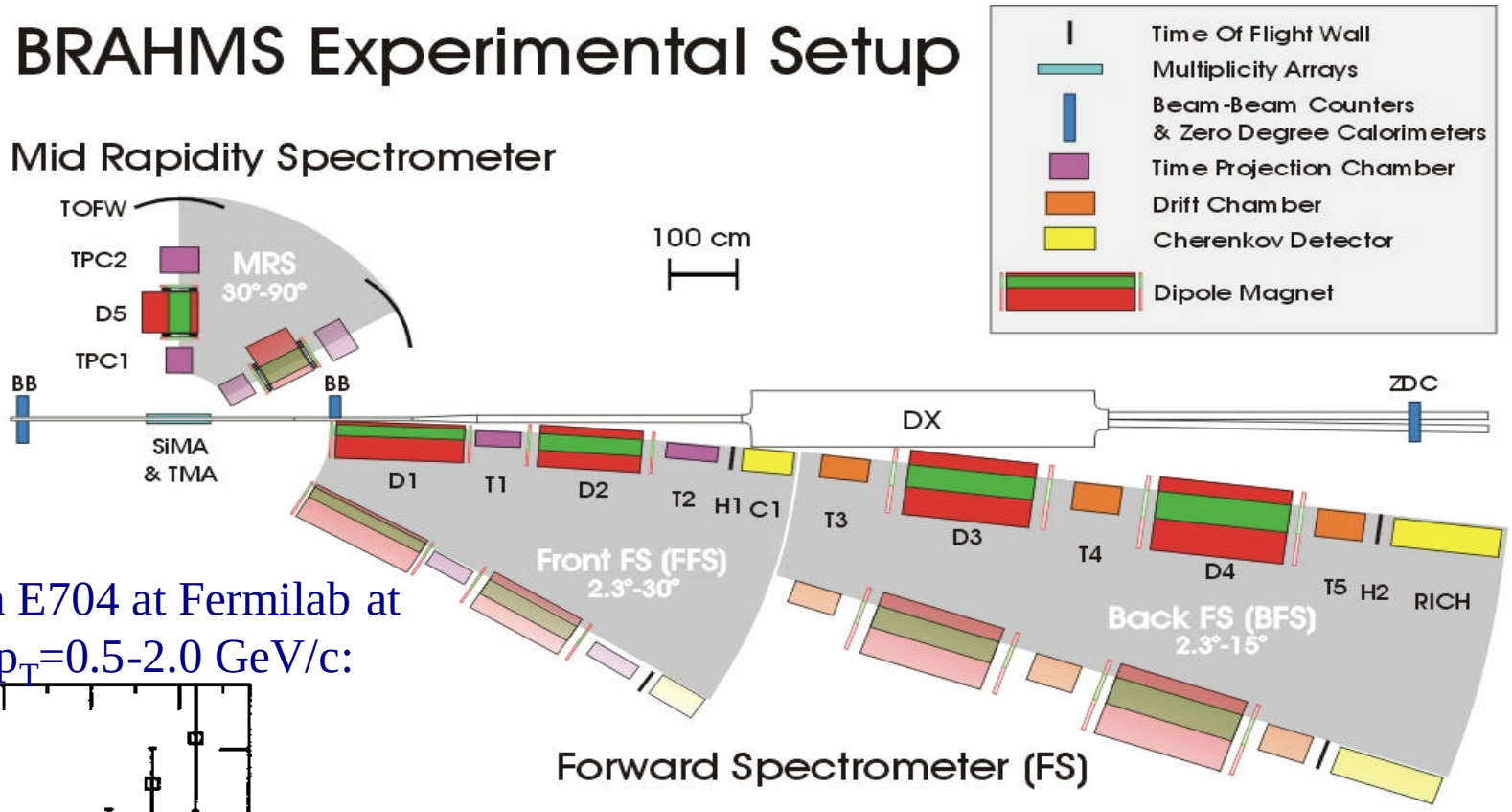


Target chamber &
beam pipe adapters

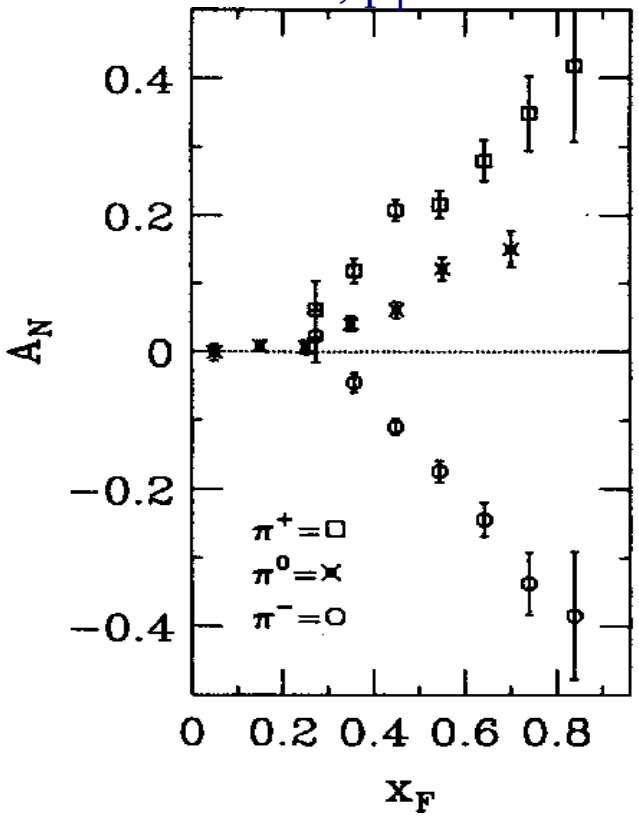
Magnet ready
for measurements



BRAHMS Experimental Setup



A_N measured in E704 at Fermilab at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:



BRAHMS proposal:

measure A_N for $p_{\uparrow}p \rightarrow \pi^{\pm} + X$ at $\sqrt{s}$=200 GeV, η_{π}~3.9

π^+ *measurements*			π^- *measurements*		
x_F	p_T(GeV/c)	Cts/hour	x_F	p_T(GeV/c)	Cts/hour
0.21	1.0	6454	0.21	1.0	5296
0.25	1.4	1068	0.25	1.4	807
0.30	1.9	163	0.30	1.9	91
0.35	2.5	24	0.35	2.5	12

Rate estimates
Assume
$\mathcal{L}$ ~ 1.5 $\mu b^{-1}s^{-1}$

Scenario for Evolution of RHIC Spin Program

RHIC Run	$\sqrt{s}$ (GeV)	$\langle \mathcal{L}_{peak} \rangle$ ($\mu b^{-1} s^{-1}$)	$\langle P_{beam} \rangle$	$\int \mathcal{L}\, dt$ (pb^{-1})	Commission
2	200	0.5	0.15 (vertical)	0.35	Snakes/polarimeters/experiments
3	200	2	0.25 (vert.+long.)	1	Rotators/AGS+local polarimeters
4+5	200	10	>0.30 (long.)	5	Pol. Jet target/spin flipper/P_{beam}/$\mathcal{L}$
>5	200	80	0.70 (long.)	320	Production
	500	200	0.70 (long.)	800	Production

Where we are in the program...

- ✓ Siberian Snakes – demonstrated to work
- P_{beam} at RHIC injection energy – now 0.4 / goal is 0.7
- ✓ Fast polarimeters in AGS and RHIC – demonstrated to work
- ✓ P_{beam} transfer AGS→RHIC – demonstrated to work
- ✓ P_{beam} preserved in RHIC ramp to 100 GeV– demonstrated to work
- P_{beam} preserved in RHIC ramp to 250 GeV – to do
- ✓ P_{beam} maintained during RHIC store – 14 hours observed
- ✓ longitudal P_{beam} at PHENIX,STAR / local polarimetry – demonstrated to work
- $\Delta P_{beam} / P_{beam}$ to ±5% – commission gas jet in 2004; ±10% in 2004; ±5% in 2005
- $\mathcal{L}_{avg\ week}$ to 20(50) pb^{-1} at $\sqrt{s}$=200(500) GeV – now ~0.3 pb^{-1} at $\sqrt{s}$=200 GeV
- Polarization reversal of stored beam – to do